Fecal Bacteria Total Maximum Daily Load Development for the Nansemond River

Primary Contact Recreational Use and Shellfish Harvesting Use

Prepared for

Virginia Department of Environmental Quality

April 26, 2006

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VADEQ, Tidewater Office

Virginia Department of Health (VDH)

Peanut Soil and Water Conservation District (PSWCD)

City of Norfolk

City of Portsmouth

Suffolk City

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Local citizens and stakeholders in the Nansemond River watershed

MapTech, Inc. of Blacksburg, Virginia, supported this study as a subcontractor to
New River-Highlands RC& D,
Through funding provided by
Virginia Department of Environmental Quality contract # 12409

EXECUTIVE SUMMARY

Background and Applicable Standards

The Nansemond River watershed, which is contained in USGS Hydrologic Unit Code 02080208, contains Suffolk and a portion of Isle of Wight County, VA. Both the Western Branch Reservoir and the Lake Meade Reservoir are located within the Nansemond River watershed. The Nansemond River drains to the lower James River basin.

The Nansemond River was first listed on the 1996 *303(d) TMDL Priority List* as not supporting the primary contact recreational use due to violations of the fecal coliform bacteria standards. This was based on results from Virginia Department of Environmental Quality (VADEQ) ambient water quality monitoring at station 2-NAN019.14. This segment extends from the Lake Meade Dam to the confluence with Shingle Creek.

Shingle Creek, a tributary to the Nansemond River, was also listed as impaired on the 1996 *303(d) TMDL Priority List* as not supporting the primary contact recreational use. The segment extends from the headwaters to the confluence with the Nansemond River. Both segments remained on the *Virginia 1996 Section 303(d) TMDL Priority List and Report* and *2002 Section 303(d) Report on Impaired Waters.* In the *2004 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* the Nansemond River (Upper) was extended to the Route 58 bridge and was renamed Nansemond River (Lake Meade Dam). The entire segment was listed for not supporting the primary contact recreational use due to violations of the fecal coliform bacteria and *enterococci* bacteria standards. A new segment was added, which includes the Lake Meade Dam segment and the Shingle Creek segment as well as the Nansemond River downstream to Sleepy Hole and other tributaries. The 3.28 square mile area of this segment, named Nansemond River and tributaries, was listed as impaired for the Virginia Department of Health (VDH) shellfish harvesting use (condemnation zone #8) due to violations of the fecal coliform bacteria standards. Shingle Creek was listed as impaired for the VADEQ primary contact recreational use and for the VDH shellfish harvesting use (a portion of condemnation zone #8) due to violations of the fecal coliform bacteria standards.

TMDL Endpoint and Water Quality Assessment

Potential sources of fecal coliform include both point source and nonpoint source contributions. Nonpoint sources include: wildlife, grazing livestock, land application of manure, land application of biosolids, urban/suburban runoff, failed and malfunctioning septic systems, and uncontrolled discharges (*i.e.* dairy parlor waste, etc.). Twenty-two(22) point sources are permitted in the Nansemond River watershed through the Virginia Pollutant Discharge Elimination System (VPDES). Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml. One method for achieving this goal is chlorination. There are 10 VPDES Confined Animal Feeding Operations (CAFO) facilities in the study area along with the streams that receive potential runoff from these facilities. None of the 10 permitted sources have direct discharges to waterways but runoff from the area could contain fecal coliform and *enterococci* bacteria.

The *enterococci* standard states that no single sample shall exceed 104-cfu/100 ml (Virginia Water Quality Standard 9 VAC 25-260-170). In addition, if data is available, the geometric mean of two or more observations taken in a calendar month should not exceed 35-cfu/100 ml *enterococci* in estuarine waters. In TMDL development, the in-stream *enterococci* targets were a geometric mean not exceeding a value of 35-cfu/100 ml and a single sample maximum of 104-cfu/100 ml. Translator equations developed by VADEQ were used to convert fecal coliform values to *enterococci* values.

The criteria to meet the VADEQ primary contact recreational use ares a geometric mean of 35 cfu/100ml *enterococci* and no single *enterococci* sample greater than 104 cfu/100ml. The VDH standards for meeting the shellfish harvesting use are: a 30-month geometric mean of 145 MPN (most probable number) and a 30-month 90^{th} percentile of 49 MPN. These were the endpoints of the impairments in the Nansemond River watershed.

Water Quality Modeling

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions in riverine and estuarine areas. The HSPF model is a continuous simulation model that can account for nonpoint source pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed for consideration of seasonal aspects of precipitation patterns within the watershed. In establishing the existing and allocation conditions, seasonal variations in hydrology, climate, and watershed activities were explicitly accounted for in the model. Due to the requirements of HSPF the Nansemond River watershed was divided into 7 subwatersheds for the purpose of modeling hydrology and water quality. The rationale for choosing these subwatersheds was based on the availability of water quality data, the impairment lengths and locations, and the limitations of the HSPF model. The flow period used for hydrologic calibration depended on the data available. A calibration period of October 1, 1997 through September 30, 2002 was used for the hydrology. Additional data was available for the discharge over Lake Meade, therefore a calibration period of January 1998 – October 2003 was used for subwatershed 1. The water quality calibration period was conducted using monitored data collected at VADEQ monitoring stations between July 1990 and June 2001.

Existing Conditions

Wildlife populations and ranges, rates of failure, locations, and number of septic systems, domestic pet populations, numbers of cattle and other livestock, and information on livestock and manure management practices for the Nansemond River watershed were all used to calculate fecal coliform loads from land-based nonpoint sources in the watershed. The estimated fecal coliform production and accumulation rates due to these sources were calculated for the watershed and incorporated into the model. To accommodate the structure of the model, calculation of the fecal coliform accumulation and source contributions on a monthly basis accounted for seasonal variation in watershed activities such as wildlife feeding patterns and land application of manure. Also, represented in the model were direct nonpoint sources of uncontrolled discharges, and direct deposition by wildlife.

Contributions from all of these sources were updated to 2006 conditions to establish existing conditions for the watershed. All runs were made using a representative precipitation record. Under existing conditions (2006), the HSPF model provided a comparable match to the VADEQ monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the watershed.

Load Allocation Scenarios

The next step in the TMDL process was to determine how to proceed from existing watershed conditions in order to reduce the various source loads to levels that would result in attainment of the water quality standards. Because United States Environmental Protection Agency (USEPA) requires a zero percent violation load allocation in TMDLs, modeling was conducted for a target value of 0% exceedance of the VADEQ *enterococci* standards and of the VDH fecal coliform standards. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Modeling of these scenarios provided predictions of whether the reductions would achieve the target of 0% exceedance. Shingle Creek requires a 97% reduction from direct wildlife loads; a 98% reduction from land-based wildlife loads; 99% reductions from direct livestock, land-based agriculture and land-based residential; and 100% reduction from direct human sources. Nansemond River (Upper) requires a 96% reduction from direct wildlife loads; a 97% reduction from land-based wildlife loads; 96% reductions from land-based agriculture and land-based residential; 0% reduction from direct livestock; and 100% reduction from direct human sources. Nansemond River (Lake Meade Dam) and Nansemond River and Tributaries both require 100% reductions from direct human sources, with no further reductions needed. The final TMDL values are shown in Tables ES.1 and ES.2.

Table ES.1 Average annual *enterococci* bacterial loads (cfu/year) modeled after TMDL allocation in the Nansemond River watershed impairments.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Shingle Creek (subwatershed 5)	2.19E+10	1.05E+13	*Implicit*	1.05E+13
VAR040044	*2.19E+10*			
Nansemond River (Upper) (subwatersheds 1,2,5)	9.99E+10	5.80E+13		5.81E+13
VA0021709	*2.18E+09*			
VA0086134	*3.14E+10*			
VAR040044	*6.63E+10*			
Nansemond River (Lake Meade Dam) (subwatersheds 1,2,3,5)	9.99E+10	4.26E+13		4.27E+13
VA0021709	*2.18E+09*			
VA0086134	*3.14E+10*			
VAR040044	*6.63E+10*			

Table ES.2 Average annual fecal coliform bacterial loads (cfu/year) modeled after TMDL allocation in the Nansemond River watershed impairments.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Shingle Creek (subwatershed 5)	2.78E+09	1.05E+13	*Implicit*	1.05E+13
VAR040044	*2.78E+09*			
Nansemond R. and Tributaries (all subwatersheds)	3.89E+10	9.47E+12		9.51E+12
VA0021709	*1.06E+09*			
VA0027138	*2.54E+09*			
VA0027146	*2.26E+09*			
VA0069302	*1.88E+09*			
VA0086134	*1.53E+10*			
VAG403000	*1.06E+08*			
VAR040044	*1.58E+10*			

Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on the Nansemond River watershed. The second step is to develop a TMDL Implementation Plan (IP). The final step is to implement the TMDL IP, and to monitor stream water quality to determine if water quality standards are being attained.

While section 303(d) of the Clean Water Act (CWA) and current United States Environmental Protection Agency regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Once a TMDL IP is developed, VADEQ will take the plan to the State Water Control Board (SWCB) for approval to implement the pollutant allocations and reductions contained in the TMDL. Also, VADEQ will request SWCB authorization to incorporate the TMDL Implementation Plan into the appropriate waterbody. With successful completion of implementation plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource.

In general, Virginia intends that the required reductions be implemented in an iterative process that first addresses those sources with the largest impact on water quality. To address the bacteria TMDL, reducing the human bacteria loading from straight pipes and failing septic systems should be a primary implementation focus because of the health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system installation/repair program. Livestock exclusion from streams has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the direct cattle deposits and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock has been shown to reduce bank erosion.

There is a measure of uncertainty associated with the final allocation development process. Monitoring performed upon completion of specific implementation milestones can provide insight into the effectiveness of implementation strategies, the need for amending the plan, and/or progress toward the eventual removal of the impairment from the 303(d) list.

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. The state must also demonstrate that attaining the designated use is not feasible. Information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens as well as EPA will be able to provide comment during this process.

Watershed stakeholders will have the opportunity to participate in the development of the TMDL Implementation Plan. While specific goals for Best Management Practices (BMPs) implementation will be established as part of the implementation plan development, the Stage I scenarios are targeted at controllable, anthropogenic bacteria.

Public Participation

During development of this report, public involvement was encouraged through two public meetings. An introduction of the agencies involved, an overview of the TMDL process, and the specific approach to developing the Nansemond River TMDLs were presented at the first of the public meetings. Details of the pollutant sources and stressor identification were also presented at this meeting. Public understanding of, and involvement in, the TMDL process was encouraged. Input from this meeting was utilized in the development of the TMDL and improved confidence in the allocation scenarios. The final model simulations and the TMDL load allocations were presented during the final public meeting. There was a 30-day public comment period beginning when the TMDL was available to the public on the DEQ website and no written comments were received. Watershed stakeholders will have the opportunity to participate in the development of the TMDL IP.

1. INTRODUCTION

1.1 Background

The need for TMDLs to be conducted in the Nansemond River watershed is based on provisions of the Clean Water Act. The document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 1991), states:

> *According to Section 303(d) of the Clean Water Act and EPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs.*
>
> *…A TMDL is a tool for implementing State water quality standards, and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

The Nansemond River watershed, which is contained in USGS Hydrologic Unit Code 02080208, contains Suffolk and a portion of Isle of Wight County, VA. Both the West Branch Reservoir and the Lake Meade Reservoir are located within the Nansemond River watershed. The Nansemond River drains to the lower James River basin (Figure 1.1).

The Nansemond River (waterbody ID# VAT-G-13E) was first listed as impaired on the 1996 *303(d) TMDL Priority List* as not supporting the primary contact recreational use due to violations of the fecal coliform bacteria standards. This was based on results from Virginia Department of Environmental Quality (VADEQ) ambient water quality monitoring at station 2-NAN019.14. This segment extends from the Lake Meade Dam to the confluence with Shingle Creek.

Shingle Creek, a tributary to the Nansemond River, was also listed as impaired on the 1996 *303(d) TMDL Priority List* as not supporting the primary contact recreational use. The segment extends from the headwaters to the confluence with the Nansemond River.

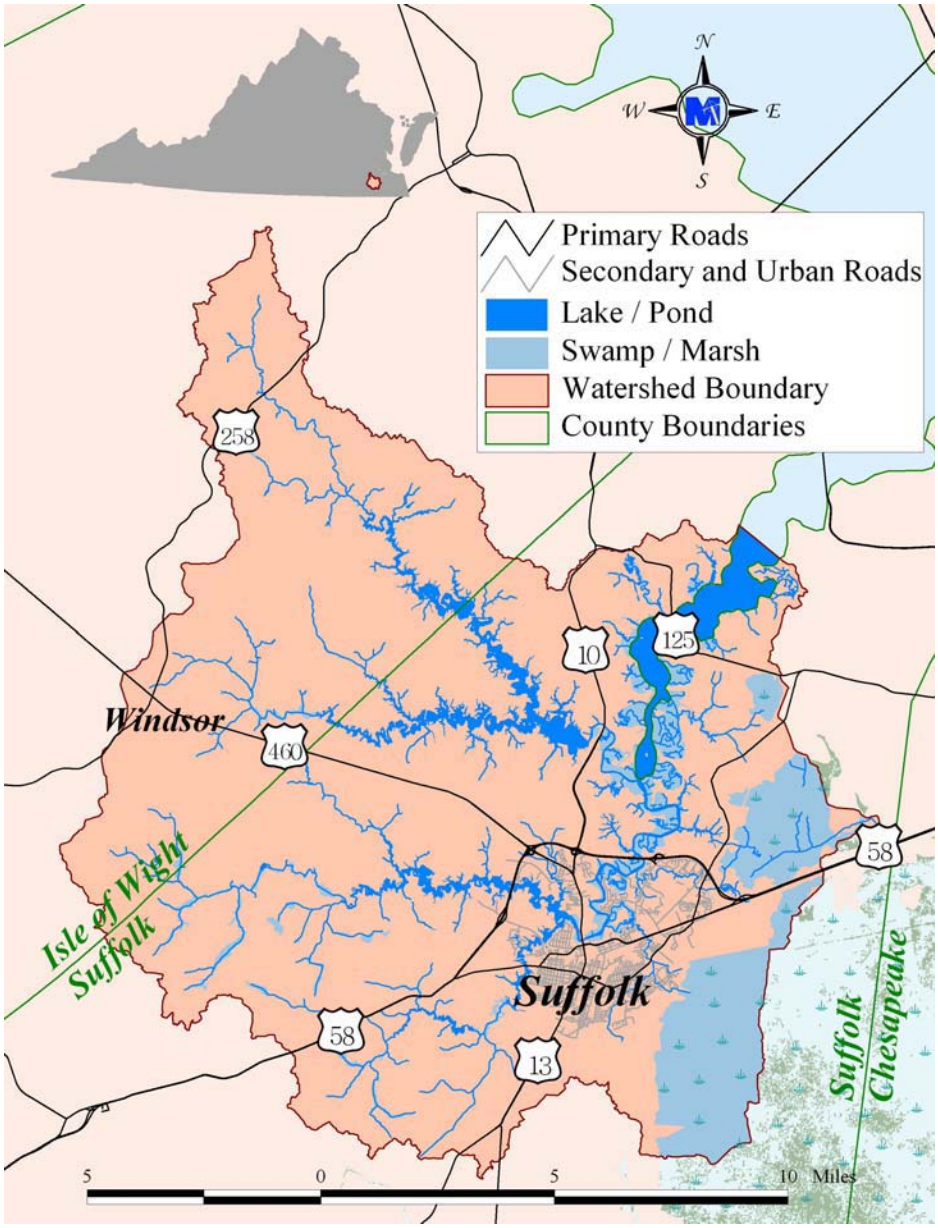

Figure 1.1 Location of the Nansemond River watershed.

In the 1998 *303(d) Total Maximum Daily Load Priority List and Report* the same segments of the Nansemond River and Shingle Creek were listed as impaired for not supporting the primary contact recreational use due to violations of the fecal coliform bacteria standards.

In the 2002 *303(d) Report on Impaired Waters* the same Nansemond River segment, called Nansemond River (Upper), was listed again for not supporting the primary contact recreational use due to violations of the fecal coliform bacteria standards. Shingle Creek was again listed as impaired for not supporting the primary contact recreational use.

In the *2004 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* the Nansemond River (Upper) impairment was extended to the Route 58 bridge and was renamed Nansemond River (Lake Meade Dam). The entire segment was listed for not supporting the primary contact recreational use due to violations of the fecal coliform bacteria and *enterococci* bacteria standards. A new segment was added to the 2004 List, which includes the Lake Meade Dam segment and the Shingle Creek segment as well as the Nansemond River downstream to Sleepy Hole and other tributaries. The 3.28 square mile area of this segment, named Nansemond River and tributaries, was listed as impaired for the VDH shellfish harvesting use (condemnation zone #8) due to violations of the fecal coliform bacteria standards. Shingle Creek was listed as impaired for the VADEQ primary contact recreational use and for the VDH shellfish harvesting use (a portion of condemnation zone #8) due to violations of the fecal coliform bacteria standards. Figure 1.2 shows the 2004 impaired segments.

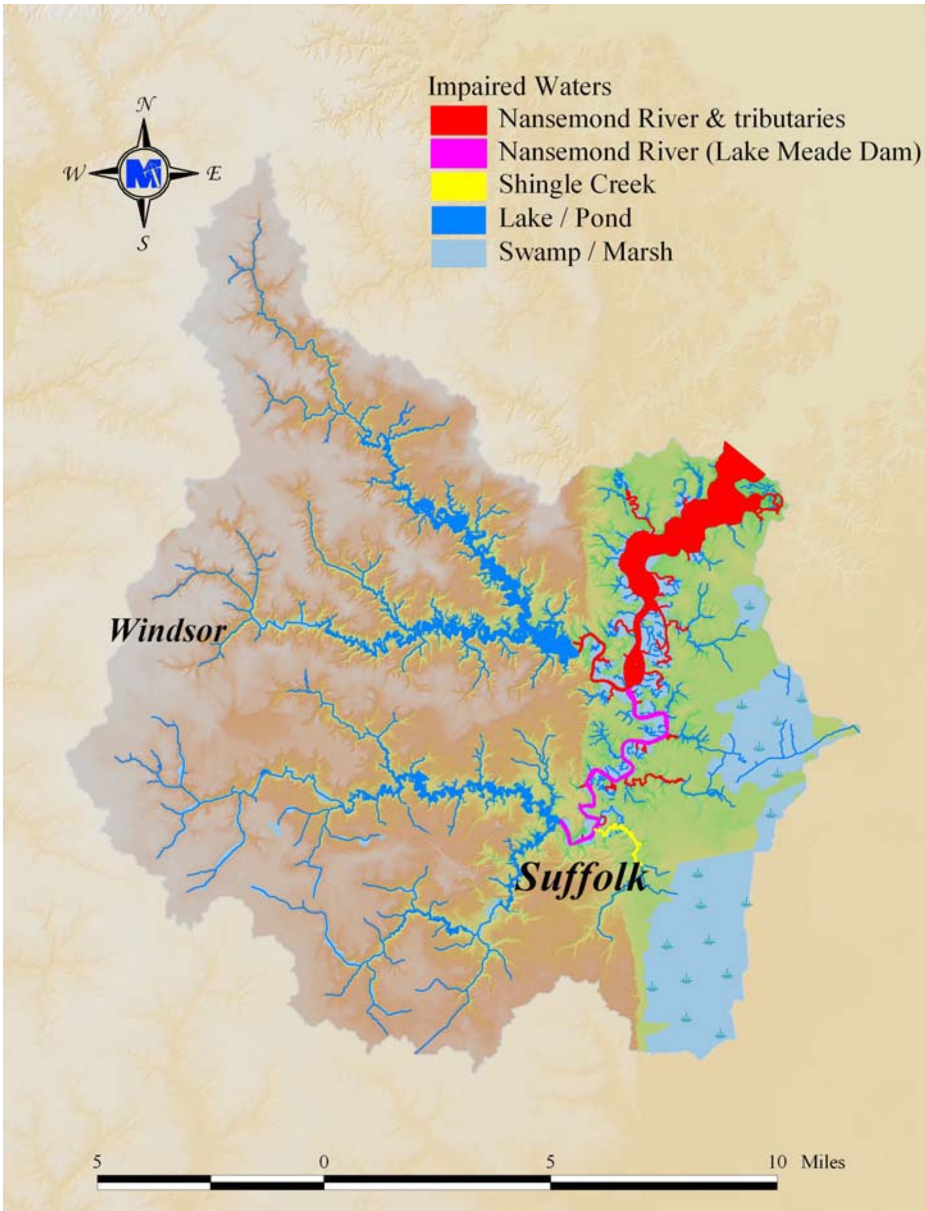

Figure 1.2 Impaired stream and estuary segments (2004) in the Nansemond River watershed.

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term "water quality standards" means "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act."

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses),

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ♦
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

Section 9 VAC 25-260-170 is the applicable water quality criteria for fecal coliform impairments in Nansemond River.

Prior to 2002, Virginia Water Quality Standards specified the following criteria for a non-shellfish supporting waterbody to be in compliance with Virginia's fecal standard for primary contact recreational use:

> *A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.*

If the waterbody had an exceedance rate > 10.5% and had at least 2 exceedances, the waterbody was classified as impaired and the development and implementation of a

TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion was applied to a particular datum or data set. If the sampling frequency was one sample or less per 30 days, the instantaneous criterion was applied; for a higher sampling frequency, the geometric criterion was applied. These were the criteria used for listing the impairments included in this study. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

The USEPA has since recommended that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. USEPA is pursuing the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tracts of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and *enterococci* standard went into effect January 15, 2003 in Virginia.

The new criteria, used in developing the bacteria TMDL in this study, is outlined in 9 VAC 25-260-170 and reads as follows

> *A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:*
>
> *1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*
>
> *2. E. coli and enterococci bacteria per 100 ml of water shall not exceed the following:*

	Geometric Mean[1]	*Single Sample Maximum*[2]
Freshwater[3]		
E. coli	*126*	*235*
Saltwater and Transition Zone[3]		
enterococci	*35*	*104*

[1] For two or more samples taken during any calendar month.
[2] No single sample maximum for *enterococci* and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.
[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

For shellfish, the criteria used for developing TMDL, is outlined in 9 VAC 25-260-160 and reads as follows.

> *In all open ocean or estuarine waters capable of propagating shellfish or in specific areas where public or leased private shellfish beds are present, and including those waters on which condemnation or restriction classifications are established by the State Department of Health, the following criteria for fecal coliform bacteria shall apply:*
>
> *The geometric mean fecal coliform value for a sampling station shall not exceed an MPN (most probable number) of 14 per 100 milliliters. The 90th percentile shall not exceed an MPN of 43 for a 5-tube, 3-dilution test or 49 for a 3-tube, 3-dilution test.*

These standards are calculated using a 30-month window, which means every consecutive 30-month data group must have a geometric mean of 14 MPN or less and a 90^{th} percentile of 49 MPN or less to meet both standards.

2.2 Selection of a TMDL Endpoint.

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the Nansemond River TMDLs, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations (section 2.1). In order to remove a waterbody from a state's list of impaired waters, the Clean Water Act requires compliance with that state's water quality standard. Since all the Nansemond River VADEQ primary contact recreational use impairments are estuarine and modeling provided simulated output of *enterococci* concentrations at 1-hour intervals, assessments of the TMDLs were made using both the geometric mean standard of 35 cfu/100 ml and the 90th percentile of 104 cfu/100 ml. Therefore, the in-stream *enterococci* targets for these TMDLs were a monthly geometric mean not exceeding 35 cfu/100 ml and a 90th percentile not exceeding 104 cfu/100 ml.

The VDH shellfish harvesting use impairments will be assessed using both the fecal coliform standard of 14 MPN and the 90th percentile of 49 MPN. Therefore, the in-stream fecal coliform targets for these TMDLs were a monthly geometric mean not exceeding 14 MPN and a 90th percentile not exceeding 49 MPN.

2.3 Selection of a TMDL Critical Condition.

USEPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Nansemond River is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken in order to meet water quality standards. Fecal bacteria sources within the Nansemond River watershed are attributed to both point and nonpoint sources. Critical conditions for waters impacted by land-based nonpoint sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context, also include nonpoint sources that are not precipitation driven (*e.g.*, fecal deposition to stream).

A graphical analysis of fecal coliform concentrations and flow duration intervals showed that there was no obvious critical flow level (Figures 2.1 through 2.3). A description of the data used in this analysis is shown in Tables 2.1 through 2.3. The analysis showed no obvious dominance of either nonpoint sources or point sources. High concentrations were recorded in all flow regimes at the three VADEQ listing stations. Based on this analysis, a time period for calibration and validation of the model was chosen based on the overall distribution of wet and dry seasons (section 4.5) in order to capture a wide range of hydrologic circumstances for all impaired streams in this study area. The resulting periods for calibration and validation for each impaired waterbody are presented in Chapter 4.

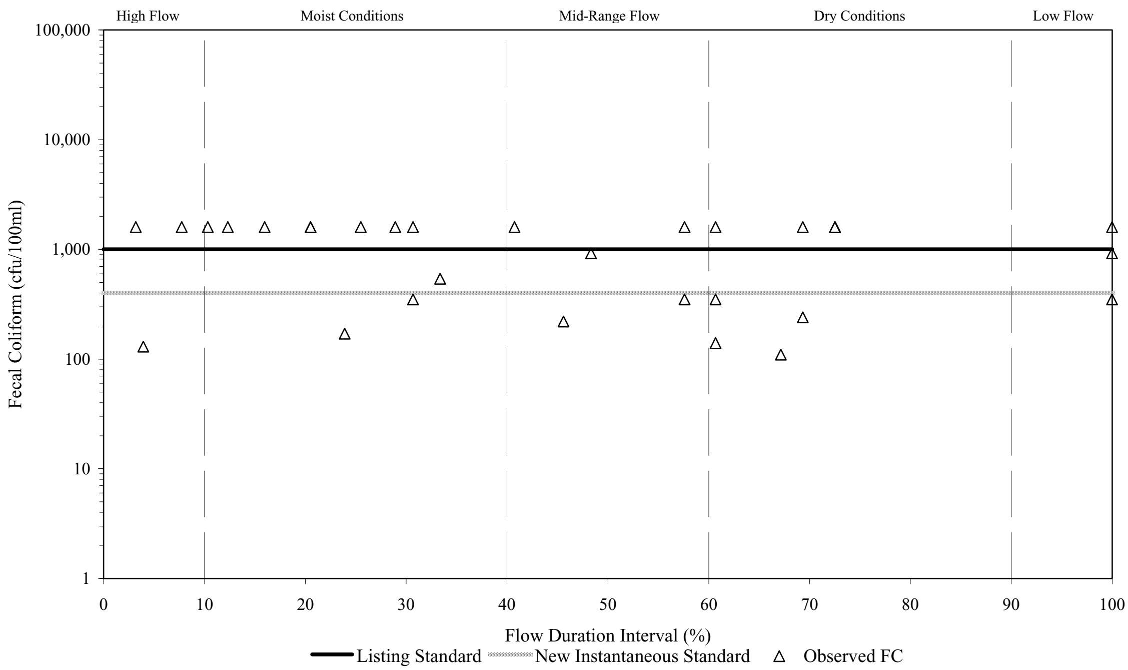

Figure 2.1 Relationship between fecal coliform concentrations (VADEQ Station 2-SGL001.50) and discharge (HSPF modeled flow at subwatershed 5) in the Shingle Creek impairment.

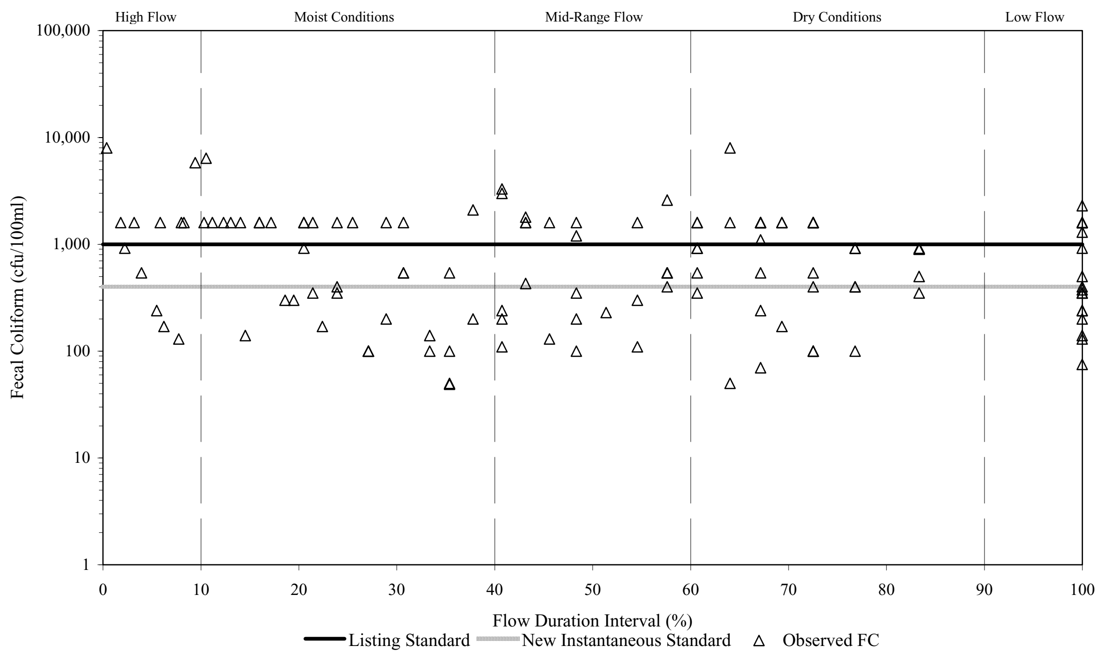

Figure 2.2 **Relationship between fecal coliform concentrations (VADEQ Station 2-SGL001.00) and discharge (HSPF modeled flow at subwatershed 5) in the Shingle Creek impairment.**

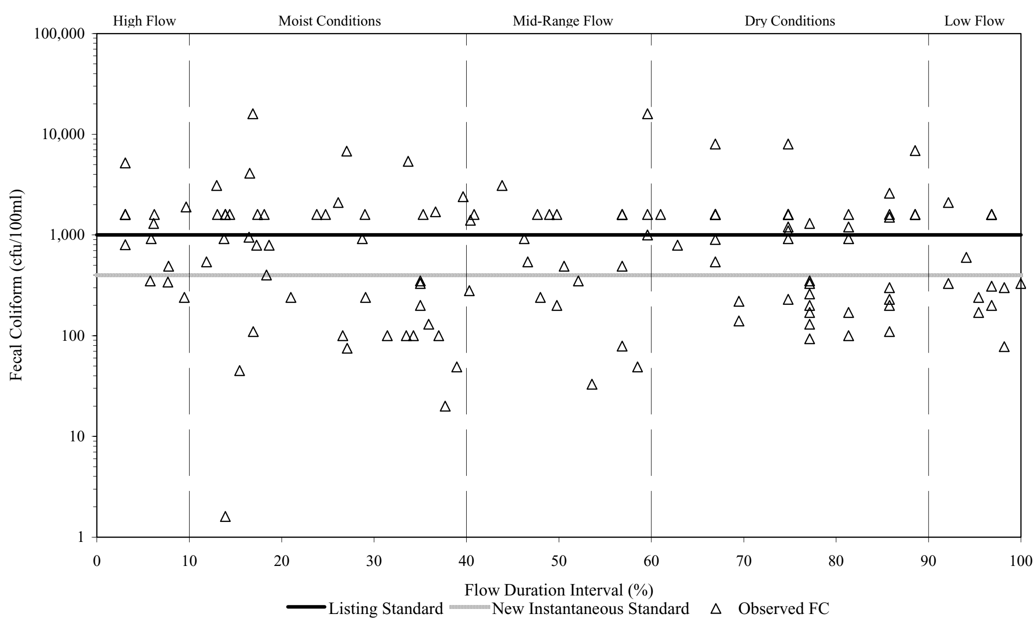

Figure 2.3 **Relationship between fecal coliform concentrations (VADEQ Station 2-NAN019.14) and discharge (HSPF modeled flow at subwatershed 2) in the Nansemond River (Lake Meade Dam) impairment.**

2.4 Discussion of In-stream Water Quality

This section provides an inventory and analysis of available observed in-stream fecal coliform monitoring data throughout the Nansemond River watershed. An examination of data from water quality stations used in the 303(d) assessment was performed and data collected by VDH were analyzed. Sources of data and pertinent results are discussed below:

2.4.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information are:

- Bacteria enumerations from 14 VADEQ in-stream monitoring stations used for TMDL assessment; and
- Bacteria enumerations from 25 VDH in-stream monitoring stations used for Shellfish condemnation zone determination; and
- Bacteria enumerations and bacterial source tracking from 6 in-stream monitoring stations.

2.4.1.1 VADEQ Water Quality Monitoring for TMDL Assessment

Data from in-stream fecal coliform samples, collected by VADEQ, were analyzed from January 1980 through December 2005 (Figure 2.4) and are included in this analysis. The stations in Figure 2.4 were included in this report because they are located on the main stem of the impaired streams. Samples were taken for the express purpose of determining compliance with the state fecal coliform instantaneous standard limiting concentrations to less than 400 cfu/100 ml. Therefore, as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 ml or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 ml, depending on the laboratory procedures employed for the sample) were not further analyzed to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 100 cfu/100 ml most likely represent concentrations below 100 cfu/100 ml, and reported concentrations of 8,000 or 16,000 cfu/100 ml most likely represent concentrations in excess of these values. Table 2.1 summarizes the fecal coliform samples collected at the in-stream monitoring stations. Table 2.2 summarizes the *E. coli* samples collected and Table 2.3 summarizes the *enterococci* samples collected.

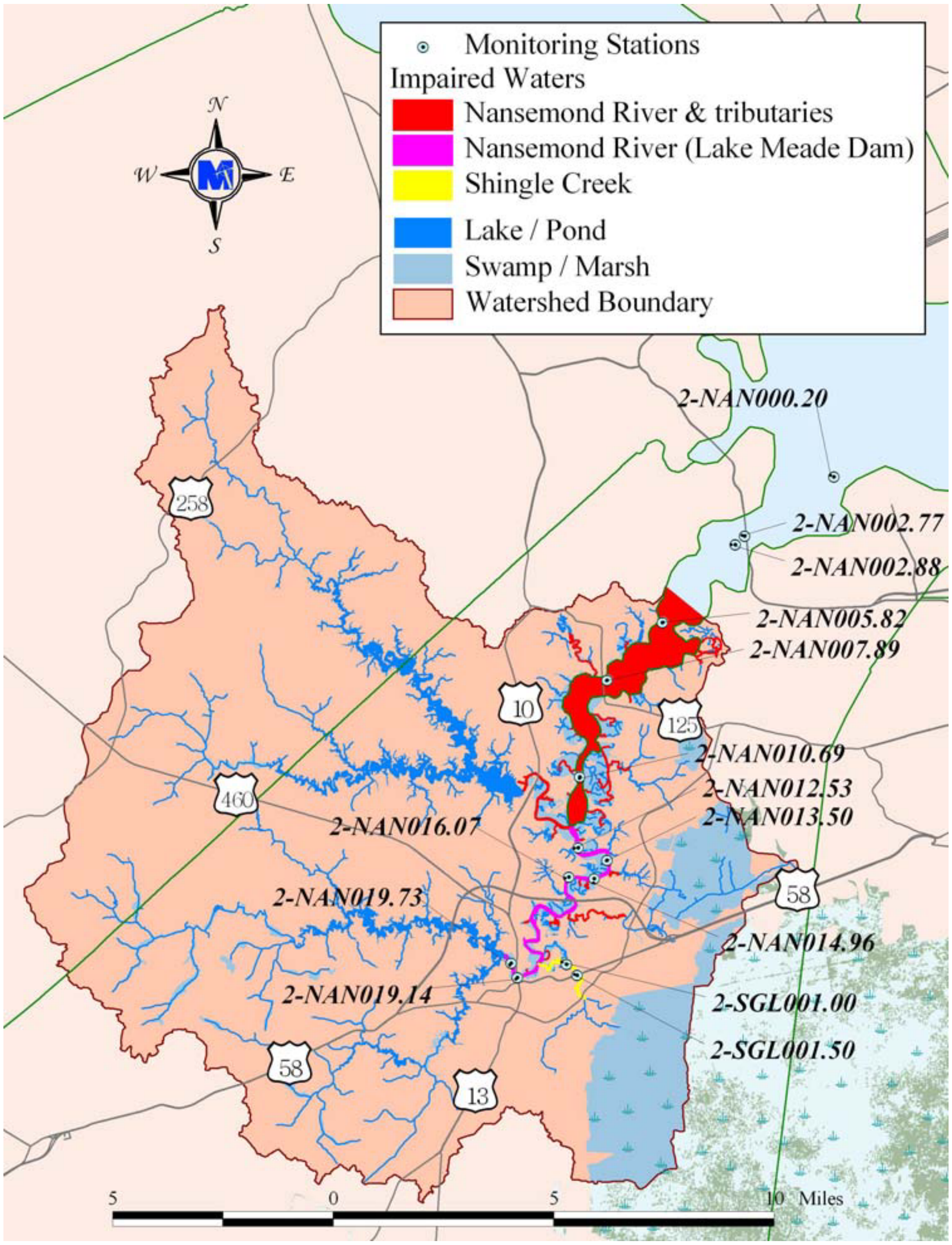

Figure 2.4 Location of VADEQ water quality monitoring stations in the Nansemond River watershed.

Table 2.1 Summary of fecal coliform monitoring conducted by VADEQ from January 1980 through October 2005.

Stream	VADEQ Station	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violation[1] (%)
Nansemond River	2-NAN000.20	137	2	540	12	4	47	1
Nansemond River	2-NAN002.77	262	2	24,000	289	14	2,103	9
Nansemond River	2-NAN002.88	20	3	93	13	4	21	0
Nansemond River	2-NAN005.82	130	2	460	35	10	85	3
Nansemond River	2-NAN007.89	136	2	920	51	23	104	1
Nansemond River	2-NAN010.69	137	2	24,400	386	75	2,092	17
Nansemond River	2-NAN012.53	95	3	1,500	251	93	319	28
Nansemond River	2-NAN013.50	33	14	16,000	727	170	2,760	15
Nansemond River	2-NAN014.96	99	9	4,600	440	230	721	33
Nansemond River	2-NAN016.07	96	9	1,100	411	240	411	44
Nansemond River	2-NAN019.14	343	1	24,000	3,303	1,500	6,054	70
Nansemond River	2-NAN019.73	51	3	11,000	1,004	460	2,093	57
Shingle Creek	2-SGL001.00	314	33	110,000	4,159	1,600	9,112	73
Shingle Creek	2-SGL001.50	31	110	1,600	1,084	1,600	641	68

[1]Violations are based on the current fecal coliform instantaneous standard (400 cfu/100mL).

Table 2.2 Summary of *E. coli* monitoring conducted by VADEQ from March 2000 through April 2004.

Stream	VADEQ Station	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violation[1] (%)
Nansemond River	2-NAN019.14	30	10	800	225	90	261	33
Shingle Creek	2-SGL001.00	9	30	800	216	160	239	22

[1]Violations are based on the current *E. coli* instantaneous standard (235 cfu/100mL).

Table 2.3 Summary of *enterococci* monitoring conducted by VADEQ from March 2000 through December 2005.

Stream	VADEQ Station	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violation[1] (%)
Nansemond River	2-NAN019.14	40	20	2,000	265	95	405	45
Shingle Creek	2-SGL001.00	19	10	2,000	371	220	473	68

[1]Violations are based on the current *enterococci* 90th percentile standard (104 cfu/100mL).

2.4.1.2 VDH Water Quality Monitoring for TMDL Assessment

Data from 25 VDH in-stream monitoring stations were analyzed from January 1990 through June 2006 (Figure 2.5) and are included in the analysis. Samples were taken for the express purpose of determining compliance with the state standards for shellfish harvesting (geomean of 14 fecal coliform MPN and a 90th percentile of 49 fecal coliform MPN). As a matter of economy, samples showing fecal coliform concentrations below 2.9 cfu/100 ml or in excess of a specified cap (1,200 cfu/100 ml) were not further analyzed to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 2.9 cfu/100 ml most likely represent concentrations below 2.9 cfu/100 ml, and reported concentrations of 1,200 cfu/100 ml most likely represent concentrations in excess of this value. Table 2.4 summarizes the fecal coliform samples collected at the VDH in-stream monitoring stations used for condemnation zone and TMDL assessment.

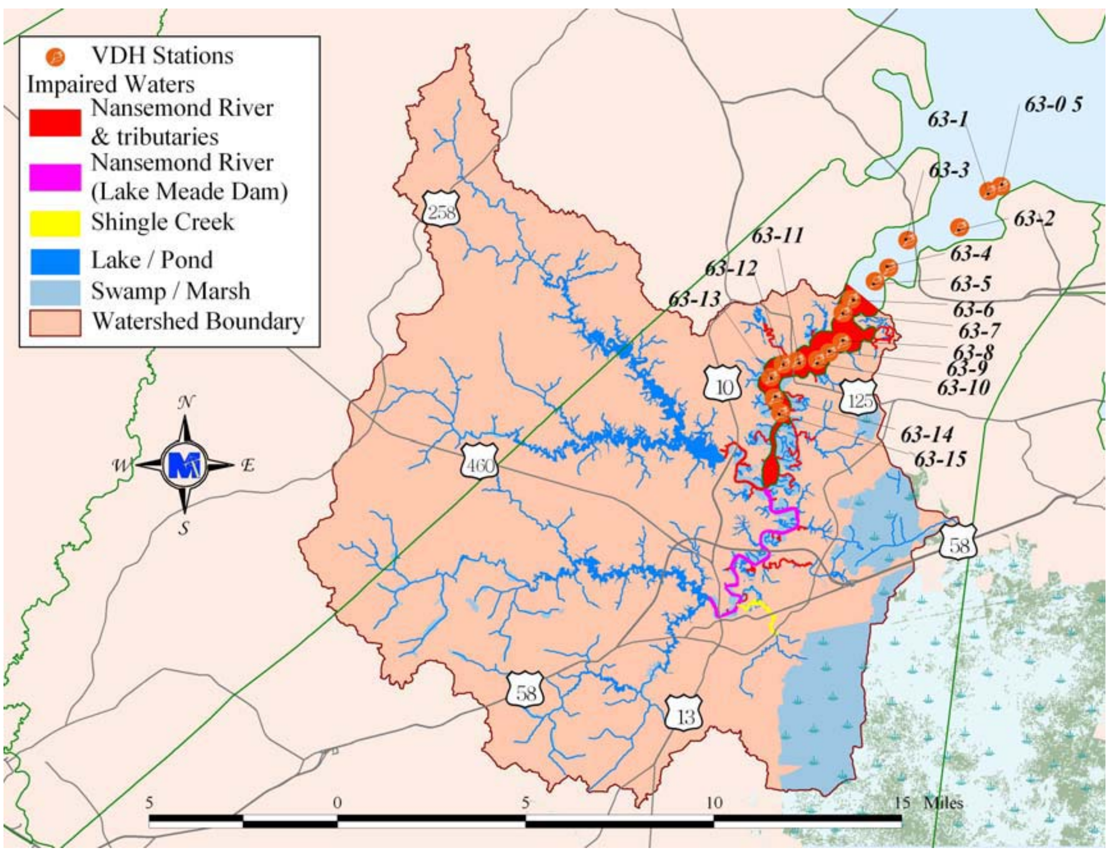

Figure 2.5 Location of VDH water quality monitoring stations in the Nansemond River watershed.

Table 2.4 Summary of fecal coliform monitoring conducted by VDH from January 1990 through January 2006.

Stream	VDH Station	Count (#)	Minimum (MPN)	Maximum (MPN)	Mean (MPN)	Median (MPN)	Geomean[1] Violation%	90th Percentile[2] Violation%
Nansemond River	63-0.5Z	177	2.9	150	9.28	3.6	0	0
Nansemond River	63-1	179	2.9	43	8.49	3.6	0	0
Nansemond River	63-1.6	17	2.9	460	47.21	23	12	12
Nansemond River	63-1A	183	2.9	1,200	29.37	9.1	1	25
Nansemond River	63-1B	141	2.9	1,200	96.16	23	89	96
Nansemond River	63-1.5Y	151	2.9	1,200	106.75	15	89	86
Nansemond River	63-1.5Z	178	2.9	460	18.36	3.6	0	6
Nansemond River	63-2	179	2.9	150	15.22	3.6	0	6
Nansemond River	63-2Z	176	2.9	460	16.63	3.6	0	5
Nansemond River	63-2A	179	2.9	240	18.39	7.3	0	18
Nansemond River	63-2.2Y	174	2.9	210	19.92	9.1	6	20
Nansemond River	63-2.4X	175	2.9	1,200	52.22	11	63	70
Nansemond River	63-2.4Y	174	2.9	1,100	32.63	9.1	17	57
Nansemond River	63-2.4Z	178	2.9	460	17.01	9.1	0	1
Nansemond River	63-3	179	2.9	460	19.06	7.3	0	0
Nansemond River	63-4	179	2.9	1,100	26.58	9.1	2	11
Nansemond River	63-5	179	2.9	150	15.74	9.1	0	0
Nansemond River	63-6	180	2.9	460	25.95	9.1	5	27
Nansemond River	63-7	180	2.9	150	20.35	9.1	8	3
Nansemond River	63-7.2	1	3.6	3.6	3.60	3.6	--	--
Nansemond River	63-7.5	20	3.6	93	37.90	39	80	90
Nansemond River	63-8	180	2.9	460	31.36	15	58	57
Nansemond River	63-9	180	2.9	1,100	42.35	23	79	58
Nansemond River	63-10	180	2.9	460	43.75	23	91	100
Nansemond River	63-11	180	2.9	1,200	55.14	23	100	88

[1]Violations are based on the current fecal coliform 30-month geomean standard (14 MPN).
[2]Violations are based on the current fecal coliform 30-month 90th percentile standard (49 MPN).
"--" insufficient data

2.4.1.3 Water Quality Monitoring Conducted During BST Report Development

The Bacterial Source Tracking (BST) process was a combined effort of sample collection and laboratory analyses from the Virginia Department of Health, the College of William and Mary's School of Marine Science/Virginia Institute of Marine Science (SMS/VIMS), and James Madison University (Wiggins, 2002). BST is intended to aid in identifying sources (*i.e.,* birds, humans, pets, livestock, or wildlife) of fecal contamination in water bodies. Data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and will improve the chances for success in implementing water quality solutions.

Over the course of a 12-month period from September 2001 through August 2002, seven sites in the Nansemond River watershed were sampled for fecal coliform on a monthly basis (Figure 2.6). Two stations are on tributaries to the Nansemond River, 1.5Y and N2.4X. As part of their routine monitoring program VDH collected both fecal and water samples. Additional fecal samples were collected by personnel from the College of William and Mary. All fecal and water samples were sent to a laboratory at William and Mary's SMS/VIMS for sample filtration, and analysis of *E. coli* values present. Filter plates for each sample were then shipped to the Department of Biology at James Madison University, for further processing using the Antibiotic Resistance Analysis (ARA) method.

Several procedures are currently under study for use in BST. Virginia has adopted the Antibiotic Resistance Analysis (ARA) methodology. This method has been demonstrated to be a reliable procedure for confirming the presence or absence of various classifications of fecal sources in watersheds in Virginia.

E. coli strains were isolated and grown in 25 concentrations of different antibiotics. Using discriminate analysis, antibiotic resistance patterns were analyzed, and results were combined into a known library of resistance patterns from these various fecal sources. Resistance patterns resulting from the unknown fecal sources sampled within the stream were then compared to this known library, in order to deduce the sources of fecal pollution.

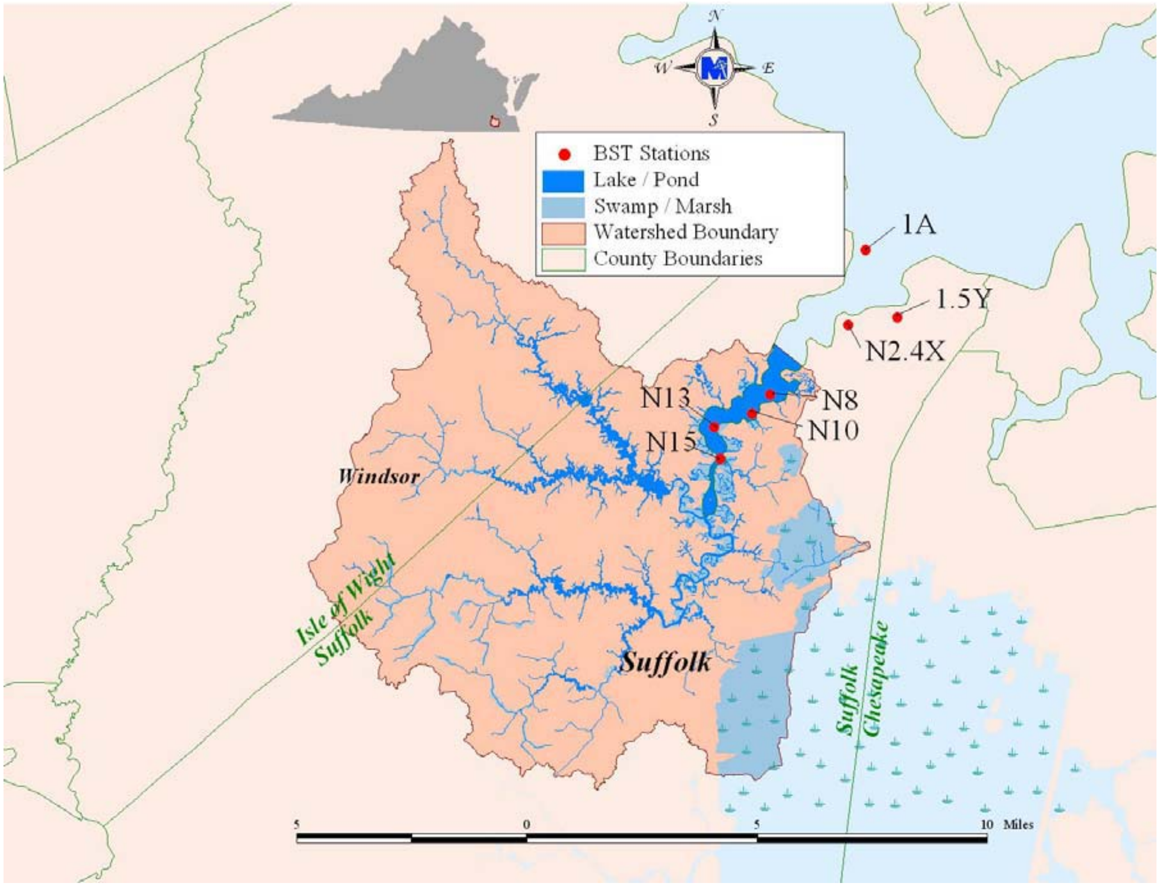

Figure 2.6 Location of BST water quality monitoring stations in the Nansemond River watershed.

The samples were tested for possible fecal contamination from bird, human, livestock, pet, and wildlife sources. The data collected were analyzed for frequency of violations, patterns in fecal source identification, and seasonal impacts. High fecal counts were noted in BST stations 1.5y, 2.4x, 13, and 15. When analyzing each source classification, human isolates were highest in January, bird isolates in June, wildlife isolates in November, and pet isolates were highest in the spring and summer months.

The BST results were reported as the percentage of isolates acquired from the sample that were identified as originating from either birds, humans, pets, livestock, or wildlife. Tables 2.4 through 2.9 summarize the *E. coli* concentrations, total number of isolates, and percentage of isolates classified for each of the five sources. The *E. coli* enumerations are given to indicate the bacteria concentrations at the time of sampling. In order to test the representativeness of the known fecal source library, and thus identify which values are statistically significant, a Minimum Detectable Percentage (MDP) was calculated. The proportions reported are formatted to indicate statistical significance (*i.e.*, **BOLD** numbers indicate a statistically significant result). The MDP shows how much misclassification exists within a library, and provides a conservative estimate of the lowest threshold for determining whether or not a particular source is a significant contributor to the watershed. Results of fecal levels below this threshold can be attributed to misclassification, while levels above this threshold reaffirm the presence of this source within the watershed. The MDP determined for the known fecal source library used for the Nansemond River watershed is 38%.

Table 2.5 Summary of bacterial source tracking results from water samples collected at station N1-A on the Nansemond River.

Site	Sample #	Date	E. coli (cfu/100 ml)	# of isolates	Percent Isolates Classified as[1]				
					Bird	Human	Livestock	Pets	Wildlife
N1-A	N001	9/26/01	1	2	**50**	**50**	0	0	0
N1-A	N008	10/25/01	3	11	36	27	9	0	27
N1-A	N015	11/27/01	12	22	5	14	55	5	23
N1-A	N022	12/12/01	40	22	**41**	27	5	14	14
N1-A	N029	1/8/02	32	23	13	**43**	4	13	26
N1-A	N036	2/6/02	3	10	10	**40**	30	20	0
N1-A	N043	3/26/02	10	23	22	17	13	**39**	9
N1-A	N050	4/23/02	1	3	33	0	33	33	0
N1-A	N057	5/21/02	5	21	38	19	0	19	24
N1-A	N064	6/6/02	0	2	**50**	0	0	**50**	0
N1-A	N071	7/17/02	0	NA[2]					
N1-A	N078	8/5/02	0	NA					

[1]Values that are bold are above the Minimum Detectable Percentage.
[2]NA= Not Applicable

Table 2.6 Summary of bacterial source tracking results from water samples collected at station N1.5-Y on the Nansemond River.

					Percent Isolates Classified as[1]				
Site	**Sample #**	**Date**	**E. coli (cfu/100 ml)**	**# of isolates**	**Bird**	**Human**	**Livestock**	**Pets**	**Wildlife**
N1.5-Y	N002	9/26/01	105	22	36	0	**55**	9	0
N1.5-Y	N009	10/25/01	4	13	38	31	0	8	23
N1.5-Y	N016	11/27/01	75	22	14	9	18	14	**45**
N1.5-Y	N023	12/12/01	440	22	**45**	9	9	18	18
N1.5-Y	N030	1/8/02	65	17	12	**47**	6	6	29
N1.5-Y	N037	2/6/02	8	22	**41**	14	36	9	0
N1.5-Y	N044	3/26/02	37	23	35	22	4	**39**	0
N1.5-Y	N051	4/23/02	111	22	23	32	0	36	9
N1.5-Y	N058	5/21/02	61	22	**41**	32	5	14	9
N1.5-Y	N065	6/6/02	3	10	**40**	10	0	20	30
N1.5-Y	N072	7/17/02	38	16	**56**	6	13	13	13
N1.5-Y	N079	8/5/02	5	17	24	12	29	6	29

[1]Values that are bold are above the Minimum Detectable Percentage.

Table 2.7 Summary of bacterial source tracking results from water samples collected at station N2.4-X on the Nansemond River.

					Percent Isolates Classified as[1]				
Site	**Sample #**	**Date**	**E.coli (cfu/100ml)**	**# of isolates**	**Bird**	**Human**	**Livestock**	**Pets**	**Wildlife**
N2.4-X	N003	9/26/01	41	23	4	4	**83**	9	0
N2.4-X	N010	10/25/01	14	22	27	32	14	14	14
N2.4-X	N017	11/27/01	26	24	13	29	17	4	38
N2.4-X	N024	12/12/01	89	22	27	0	5	27	**41**
N2.4-X	N031	1/8/02	21	22	**50**	5	14	5	27
N2.4-X	N038	2/6/02	4	11	18	**55**	9	9	9
N2.4-X	N045	3/26/02	19	23	9	**39**	13	4	35
N2.4-X	N052	4/23/02	108	23	13	17	4	22	**43**
N2.4-X	N059	5/21/02	35	21	33	19	24	5	19
N2.4-X	N066	6/6/02	12	23	13	22	0	22	**43**
N2.4-X	N073	7/17/02	28	23	22	9	22	17	30
N2.4-X	N080	8/5/02	15	20	0	35	10	5	**50**

[1]Values that are bold are above the Minimum Detectable Percentage.

Table 2.8 Summary of bacterial source tracking results from water samples collected at station N-8 on the Nansemond River.

Site	Sample #	Date	E. coli (cfu/100ml)	# of isolates	Bird	Human	Livestock	Pets	Wildlife
					Percent Isolates Classified as[1]				
N-8	N004	9/26/01	6	6	17	33	0	33	17
N-8	N011	10/25/01	11	24	38	13	4	17	29
N-8	N018	11/27/01	3	8	0	25	38	13	25
N-8	N025	12/12/01	47	23	13	4	0	13	**70**
N-8	N032	1/8/02	17	20	15	**55**	10	5	15
N-8	N039	2/6/02	2	25	**44**	16	8	16	16
N-8	N046	3/26/02	3	15	27	**40**	0	20	13
N-8	N053	4/23/02	46	22	18	23	9	32	18
N-8	N060	5/21/02	18	20	30	15	0	30	25
N-8	N067	6/6/02	3	11	**82**	18	0	0	0
N-8	N074	7/17/02	8	23	26	4	26	13	30
N-8	N081	8/5/02	3	13	8	**46**	0	**46**	0

[1]Values that are bold are above the Minimum Detectable Percentage.

Table 2.9 Summary of bacterial source tracking results from water samples collected at station N-10 on the Nansemond River.

Site	Sample #	Date	E. coli (cfu/100 ml)	# of isolates	Bird	Human	Livestock	Pets	Wildlife
					Percent Isolates Classified as[1]				
N-10	N005	9/26/01	7	7	29	29	14	0	29
N-10	N012	10/25/01	4	19	26	16	32	21	5
N-10	N019	11/27/01	3	11	0	9	36	0	**55**
N-10	N026	12/12/01	61	23	**48**	17	9	13	13
N-10	N033	1/8/02	27	24	8	**50**	25	4	13
N-10	N040	2/6/02	4	17	29	35	29	6	0
N-10	N047	3/26/02	3	11	18	**45**	9	9	18
N-10	N054	4/23/02	44	23	**39**	**39**	4	13	4
N-10	N061	5/21/02	19	21	14	24	19	24	19
N-10	N068	6/6/02	5	18	33	17	0	28	22
N-10	N075	7/17/02	8	23	22	4	30	17	26
N-10	N082	8/5/02	1	2	0	**50**	0	**50**	0

[1]Values that are bold are above the Minimum Detectable Percentage.

Table 2.10 Summary of bacterial source tracking results from water samples collected at station N-13 on the Nansemond River.

Site	Sample #	Date	E. coli (cfu/100 ml)	# of isolates	Percent Isolates Classified as[1] Bird	Human	Livestock	Pets	Wildlife
N-13	N006	9/26/01	16	17	18	29	24	12	18
N-13	N013	10/25/01	30	23	26	22	9	13	30
N-13	N020	11/27/01	16	24	0	13	29	13	**46**
N-13	N027	12/12/01	310	22	23	14	18	32	14
N-13	N034	1/8/02	135	22	36	**55**	5	5	0
N-13	N041	2/6/02	5	14	21	**50**	14	7	7
N-13	N048	3/26/02	30	23	22	13	17	26	22
N-13	N055	4/23/02	115	23	**43**	22	0	30	4
N-13	N062	5/21/02	55	22	18	**55**	14	5	9
N-13	N069	6/6/02	12	23	**57**	17	9	17	0
N-13	N076	7/17/02	16	24	4	38	4	4	**50**
N-13	N083	8/5/02	1	4	0	0	25	**75**	0

[1]Values that are bold are above the Minimum Detectable Percentage.

Table 2.11 Summary of bacterial source tracking results from water samples collected at station N-15 on the Nansemond River.

Site	Sample #	Date	E. coli (cfu/100 ml)	# of isolates	Percent Isolates Classified as[1] Bird	Human	Livestock	Pets	Wildlife
N-15	N007	9/26/01	43	22	**41**	9	27	14	9
N-15	N014	10/25/01	57	23	4	9	22	9	**57**
N-15	N021	11/27/01	59	24	0	33	13	17	38
N-15	N028	12/12/01	1155	24	**42**	29	0	21	8
N-15	N035	1/8/02	110	21	**43**	**43**	10	5	0
N-15	N042	2/6/02	14	23	**43**	30	9	9	9
N-15	N049	3/26/02	30	24	38	13	8	33	8
N-15	N056	4/23/02	145	23	35	**52**	0	4	9
N-15	N063	5/21/02	69	23	9	30	17	22	22
N-15	N070	6/6/02	8	22	**59**	9	9	18	5
N-15	N077	7/17/02	17	24	4	29	4	25	38
N-15	N084	8/5/02	14	24	0	**54**	0	25	21

[1]Values that are bold are above the Minimum Detectable Percentage.

Table 2.12 summarizes the results for each station with load-weighted average proportions of bacteria originating from the five source categories. The load-weighted average considers the concentration of *E. coli* measured, the number of bacterial isolates analyzed in the BST analysis, and the percentage of each source from all samples.

Table 2.12 Load weighted average proportions of fecal bacteria originating from bird, human, wildlife, pet, and livestock sources.

Station ID	Weighted Averages: Bird	Human	Wildlife	Pet	Livestock
N 1-A	25%	29%	19%	15%	12%
N 1.5-y	36%	15%	16%	19%	14%
N2.4-X	19%	14%	33%	17%	17%
N-8	20%	18%	36%	21%	5%
N-10	33%	30%	12%	13%	12%
N-13	28%	27%	12%	22%	11%
N-15	37%	31%	11%	18%	3%

The conclusive results of the BST analyses show that birds and humans are significant contributors of fecal contamination in the Nansemond River watershed. There were 20 human source samples and 19 bird source samples out of the 84 total samples collected, with percentages exceeding the Minimum Detectable Percentage of 38%. Given the land use of the watershed, the urban populations, and large amounts of swamp and estuarine areas that attract large numbers of birds, these results appear well-founded.

2.4.2 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on precipitation, discharge, and fecal coliform concentrations. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month.

A seasonal analysis of precipitation, discharge, and fecal coliform concentration data were conducted using the Mood's Median Test (Minitab, 1995). This test was used to compare median values of precipitation and fecal coliform concentrations in each month. Significant differences between months within years were reported.

2.4.2.1 Precipitation

Total monthly precipitation measured at stations Suffolk Lake Kilby #448192 in Suffolk City, Holland 1 E #444044 in Suffolk City, and Driver 4 NE #442504 in Suffolk City was analyzed and no overall, long-term trends were found (Table 2.13).

Table 2.13 Summary of trend analysis on precipitation (in).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
448192	3.974	3.500	23.060	0.000	2.310928	667	No Trend
442504	3.873	3.440	15.870	0.530	2.478861	94	No Trend
444044	4.037	3.570	23.470	0.210	2.29683	667	No Trend

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope

Mood's Median tests were performed on each station to identify any seasonality effect within the precipitation data. Significant seasonality effects were found at stations #448192 and #444044. Differences in mean monthly precipitation are indicated in Tables 2.14 and 2.15. Precipitation values, at a given station, in months with the same median group letter are not significantly different from each other at a 95% significance level. For example, at station #448192 January, February, March, April, May, September, October, November, and December are all in median group "A" and are not significantly different from each other. In months with multiple groups, precipitation values are the result of the 95% confidence interval, for that month, overlapping more than one median group. For example, at station #448192, precipitation during the months of June, and July is classified in both median group "A" and "B" and is not significantly different than either group. Station #442504 did not have a significant seasonality effect.

Table 2.14 Summary of the Mood's Median Test on mean monthly precipitation at station 448192 (p=0.001).

Month	Mean	Min	Max	Median Group	
January	3.80	0.67	9.05	A	
February	3.56	0.75	7.93	A	
March	4.13	0.93	11.18	A	
April	3.19	0.38	7.22	A	
May	3.80	0.90	7.92	A	
June	4.15	0.29	10.13	A	B
July	5.17	1.30	12.21	A	B
August	5.51	0.00	19.22		B
September	4.52	0.18	23.06	A	
October	3.48	0.02	12.24	A	
November	3.05	0.25	7.40	A	
December	3.36	0.52	7.03	A	

Table 2.15 Summary of the Mood's Median Test on mean monthly precipitation at station 444044 (p=0.001).

Month	Mean	Min	Max	Median Group	
January	3.92	0.55	8.63	A	
February	3.49	0.23	7.39	A	
March	3.91	0.91	10.13	A	
April	3.32	0.80	6.63	A	
May	3.83	0.65	10.01	A	
June	4.20	0.33	10.61	A	B
July	5.78	1.32	13.75		B
August	5.75	0.73	15.57	A	B
September	4.49	0.21	23.47	A	
October	3.41	0.03	12.72	A	
November	3.09	0.29	8.32	A	
December	3.24	0.56	6.52	A	

2.4.2.2 Fecal Coliform Concentrations

Water quality monitoring data collected by VADEQ were described in section 2.2.1.1. The trend analysis was conducted on data collected at stations used in TMDL assessment, where sufficient data was available. A significant trend was found at stations 2NAN002.77, 2NAN019.14, and 2SGL001.00, while all other stations had no overall trends (Table 2.16). A negative slope is associated with each instance of a significant trend (stations 2NAN002.77, 2NAN019.14, and 2SGL001.00), indicating a significant decrease in fecal coliform over time.

Table 2.16 Summary of trend analysis on fecal coliform (cfu).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
2-NAN000.20	13.52	3.6	540.0	1.8	50.72	116	No Trend
2-NAN002.77	232.41	13.0	24,000	1.8	1,864.2	167	-1.88
2-NAN005.82	32.01	9.1	460.0	1.8	77.0	128	No Trend
2-NAN007.89	52.53	23.0	920.0	1.8	109.20	116	No Trend
2-NAN010.69	306.96	75.0	12,205	1.8	1,163.3	115	No Trend
2-NAN012.53	254.21	93.0	1,100	3.0	301.33	79	No Trend
2-NAN014.96	418.34	240.0	4,600	9.1	623.18	78	No Trend
2-NAN016.07	422.17	240.0	1,100	9.1	412.87	76	No Trend
2-NAN019.14	2,791.4	1,246.5	24,000	1.6	5,131.8	251	-59.24
2-NAN019.73	873.67	460.0	11,000	3.0	1,800.5	36	--
2-SGL001.00	3,014.1	1,300.0	78,000	33.0	6,769.6	253	-81.43

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data

Mood's Median tests were performed on each station to identify any seasonality effect within the fecal coliform data collected by VADEQ. Significant seasonality effects were found at stations 2NAN000.20, 2NAN007.89, 2NAN019.14, and 2NAN019.73. Differences in mean monthly fecal coliform values are indicated in Tables 2.17, 2.187, 2.19 and 2.20. Fecal coliform values, at a given station, in months with a different median group letter are significantly different from each other at a 95% significance level. For example, at station 2NAN000.20, January is in median group "B", while June is in median group "A", hence the fecal coliform values in January are significantly different from the fecal coliform values in June. In months with multiple groups, fecal coliform values are the result of the 95% confidence interval, for that month, overlapping more than one median group. For example, at station 2NAN000.20, fecal coliform values during the months of February, March, April, May, July, August, September, October, November, and December are classified in both median group "A" and "B" and are not significantly different than either group. Stations 2NAN002.77, 2NAN007.89, 2NAN010.69, 2NAN012.53, 2AN014.96, 2NAN016.07, and 2SGL001.00 did not have significant seasonality effects.

Table 2.17 Summary of Mood's Median Test on mean monthly fecal coliform at 2NAN000.20 on Nansemond River (p=0.008).

Month	Mean	Min	Max	Median Group	
January	18.11	3.60	91.00		B
February	8.86	1.80	34.00	A	B
March	9.65	3.60	23.00	A	B
April	13.30	2.00	43.00	A	B
May	5.13	1.80	15.00	A	B
June	2.78	1.80	4.50	A	
July	5.13	3.00	9.10	A	B
August	5.01	1.80	18.00	A	B
September	9.62	3.00	36.00	A	B
October	55.75	2.00	540.00	A	B
November	13.86	3.00	43.00	A	B
December	11.90	2.00	23.00	A	B

Table 2.18 Summary of Mood's Median Test on mean monthly fecal coliform at 2NAN007.89 on Nansemond River (p=0.030).

Month	Mean	Min	Max	Median Group	
January	21.28	3.00	43.00	A	B
February	36.89	1.80	350.00	A	
March	33.94	3.60	43.00		B
April	70.48	3.60	240.00	A	B
May	39.59	7.30	170.00	A	B
June	29.59	2.00	150.00	A	B
July	16.12	3.00	43.00	A	B
August	47.72	2.00	240.00	A	B
September	21.33	3.00	43.00	A	B
October	109.42	9.10	920.00	A	B
November	133.33	13.00	460.00	A	B
December	47.30	2.00	240.00	A	B

Table 2.19 Summary of Mood's Median Test on mean monthly fecal coliform at 2NAN019.14 on Nansemond River (p=0.021).

Month	Mean	Min	Max	Median Group	
January	1,431	3.0	6,700	A	B
February	1,722	20.0	17,500	A	B
March	3,186	78.0	24,000	A	B
April	1,055	33.0	6,250	A	
May	2,054	230.0	11,000	A	B
June	3,552	380.0	24,000		B
July	3,624	11.3	16,000	A	B
August	3,949	6.5	24,000	A	B
September	3,453	1.6	16,153	A	B
October	4,308	100.0	24,000	A	B
November	3,637	170.0	24,000	A	B
December	1,434	50.0	7,800	A	B

Table 2.20 Summary of Mood's Median Test on mean monthly fecal coliform at 2NAN019.73 on Nansemond River (p=0.046).

Month	Mean	Min	Max	Median Group	
January	336.5	3.0	1,100	A	B
February	95.3	23.0	240	A	
March	736.4	9.1	1,100	A	B
April	43.0	43.0	43.0	A	
May	600.0	240.0	1,100	A	B
June	3,575.0	1,100.0	11,000		B
July	586.7	230.0	1,100	A	B
August	1,015.0	930.0	1,100		B
September	670.0	240.0	1,100	A	B
October	1,100.0	1,100.0	1,100		B
November	470.8	93.0	1,100	A	B
December	6.05	3.0	9.10	A	

2.4.2.3 Enterococci Concentrations

Water quality monitoring data collected by VADEQ and VDH were described in section 2.4.1.2. The trend analysis was conducted on data, if sufficient, collected at stations used in TMDL assessment. Station 63-2.4X had a significant trend with a positive slope, indicating a general increase in *enterococci* values over time (Table 2.21). All other stations had no significant overall trend.

Table 2.21 Summary of trend analysis on *enterococci* (cfu).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
2NAN019.14	270.0	100.0	2,000	20.0	409.26	39	--
63-0.5Z	9.28	3.6	150	2.9	17.72	177	No Trend
63-1	8.49	3.6	43.0	2.9	9.78	179	No Trend
63-1A	29.94	9.1	1,200	2.9	99.78	179	No Trend
63-1B	97.47	23.0	1,200	2.9	232.68	137	No Trend
63-1.5Y	106.75	15.0	1,200	2.9	274.82	151	No Trend
63-1.5Z	18.36	3.6	460.0	2.9	47.37	178	No Trend
63-2	15.22	3.6	150.0	2.9	22.50	179	No Trend
63-2Z	16.63	3.6	460.0	2.9	39.82	176	No Trend
63-2A	18.39	7.3	240.0	2.9	33.21	179	No Trend
63-2.2Y	19.92	9.1	210.0	2.9	33.24	174	No Trend
63-2.4X	52.22	11.0	1,200	2.9	160.68	175	0.233
63-2.4Y	32.63	9.1	1,100	2.9	96.84	174	No Trend
63-2.4Z	17.01	9.1	460.0	2.9	38.89	178	No Trend
63-3	19.06	7.3	460.0	2.9	51.18	179	No Trend
63-4	26.58	9.1	1,100	2.9	92.52	179	No Trend
63-5	15.74	9.1	150.0	2.9	20.49	179	No Trend
63-6	25.95	9.1	460.0	2.9	49.58	180	No Trend
63-7	20.35	9.1	150.0	2.9	24.81	180	No Trend
63-8	31.36	15.0	460.0	2.9	58.11	180	No Trend
63-9	42.35	23.0	1,100	2.9	102.34	180	No Trend
63-10	43.75	23.00	460.0	2.9	74.31	180	No Trend
63-11	55.14	23.0	1,200	2.9	137.17	180	No Trend

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data

Mood's Median tests were performed on each station to identify any seasonality effect within the *enterococci* data collected by VDH. Significant seasonality effects were found at stations 63-1, 63-1A, 63-2, 63-2Z, 63-2A, 63-2.4X, 63-2.4Z, 63-3, 63-4, 63-5, 63-6, 63-7, 63-10, and 63-11. Differences in mean monthly *enterococci* values are indicated in Tables 2.22, through 2.35. *Enterococci* values, at a given station, in months with the same median group letter are not significantly different from each other at a 95% significance level. For example, at station 63-1, *enterococci* values in May, June, July, August, and September are all in median group "A" and are not significantly different from each other. In months with multiple groups, *enterococci* values are the result of the 95% confidence interval, for that month, overlapping more than one median group. For example, at station 63-1, *enterococci* values during the months of January, February, March, April, October, and November are classified in both median group "A" and "B" and are not significantly different than either group. Stations 2NAN019.14, 63-0.5Z, 63-

1B, 63-1.5Y, 63-1.5Z, 63-2.2Y, 63-2.4Y, 63-8, and 63-9 did not have significant seasonality effects.

Table 2.22 Summary of Mood's Median Test on mean monthly *enterococci* at 63-1 on Nansemond River (p=0.001).

Month	Mean	Min	Max	Median Group	
January	11.23	2.90	43.00	A	B
February	9.68	2.90	43.00	A	B
March	7.15	2.90	23.00	A	B
April	12.85	2.90	43.00	A	B
May	4.69	2.90	15.00	A	
June	3.90	2.90	9.10	A	
July	8.61	2.90	43.00	A	
August	3.09	2.90	3.60	A	
September	5.43	2.90	23.00	A	
October	10.01	2.90	23.00	A	B
November	10.09	2.90	39.00	A	B
December	15.51	2.90	43.00		B

Table 2.23 Summary of Mood's Median Test on mean monthly *enterococci* at 63-1A on Nansemond River (p=0.001).

Month	Mean	Min	Max	Median Group	
January	36.08	2.90	240.00	A	B
February	26.06	2.90	240.00	A	B
March	14.53	2.90	43.00	A	B
April	13.17	2.90	43.00	A	B
May	6.59	2.90	23.00	A	
June	3.55	2.90	9.10	A	
July	78.97	2.90	1,200	A	
August	3.71	2.90	9.10	A	
September	10.91	2.90	43.00	A	
October	77.85	3.00	240.00		B
November	24.71	2.90	75.00	A	B
December	57.45	2.90	240.00	A	B

Table 2.24 Summary of Mood's Median Test on mean monthly *enterococci* at 63-2 on Nansemond River (p=0.001).

Month	Mean	Min	Max	Median Group	
January	18.72	2.90	43.00		B
February	6.39	2.90	23.00	A	B
March	14.68	2.90	93.00	A	B
April	13.34	3.00	43.00	A	B
May	7.97	2.90	43.00	A	B
June	13.48	2.90	150.00	A	
July	16.09	2.90	93.00	A	B
August	2.95	2.90	3.60	A	
September	11.39	2.90	75.00	A	B
October	33.91	2.90	93.00	A	B
November	20.48	3.60	75.00	A	B
December	22.51	2.90	43.00		B

Table 2.25 Summary of Mood's Median Test on mean monthly *enterococci* at 63-2Z on Nansemond River (p=0.040).

Month	Mean	Min	Max	Median Group	
January	21.71	2.90	93.00	A	B
February	6.15	2.90	23.00	A	B
March	17.03	2.90	93.00	A	B
April	25.53	2.90	150.00		B
May	11.27	2.90	43.00	A	B
June	15.11	2.90	93.00	A	
July	9.08	2.90	43.00	A	B
August	6.43	2.90	23.00	A	B
September	12.41	2.90	43.00	A	B
October	41.46	2.90	460.00	A	B
November	24.66	2.90	93.00	A	B
December	9.56	2.90	43.00	A	B

Table 2.26 Summary of Mood's Median Test on mean monthly *enterococci* at 63-2A on Nansemond River (p=0.001).

Month	Mean	Min	Max	Median Group	
January	26.26	3.60	240.00	A	B
February	13.05	2.90	75.00	A	B
March	10.24	2.90	28.00	A	B
April	31.69	2.90	150.00		B
May	10.62	2.90	93.00	A	
June	10.01	2.90	93.00	A	
July	32.18	2.90	240.00	A	B
August	5.04	2.90	15.00	A	
September	14.72	2.90	93.00	A	B
October	19.94	2.90	93.00	A	B
November	16.66	3.60	43.00		B
December	28.89	2.90	93.00		B

Table 2.27 Summary of Mood's Median Test on mean monthly *enterococci* at 63-2.4X on Nansemond River (p=0.024).

Month	Mean	Min	Max	Median Group	
January	82.10	2.90	1,100	A	B
February	14.46	2.90	93.00	A	
March	17.99	2.90	75.00	A	B
April	53.63	3.60	240.00		B
May	111.60	2.90	1,200	A	B
June	118.71	2.90	1,200	A	B
July	72.61	2.90	460.00	A	B
August	23.21	2.90	43.00	A	B
September	13.85	2.90	43.00	A	B
October	35.15	2.90	210.00	A	B
November	22.48	2.90	75.00	A	B
December	34.53	2.90	210.00	A	

Table 2.28 Summary of Mood's Median Test on mean monthly *enterococci* at 63-2.4Z on Nansemond River (p=0.002).

Month	Mean	Min	Max	Median Group	
January	19.35	2.90	93.00	A	B
February	8.21	2.90	43.00	A	B
March	13.34	2.90	93.00	A	B
April	26.51	3.60	93.00	A	B
May	8.61	2.90	43.00	A	
June	34.36	2.90	460.00	A	B
July	16.06	2.90	93.00	A	B
August	8.27	2.90	43.00	A	
September	7.90	2.90	23.00	A	B
October	17.88	2.90	93.00	A	B
November	20.71	2.90	75.00	A	B
December	21.50	3.60	93.00		B

Table 2.29 Summary of Mood's Median Test on mean monthly *enterococci* at 63-3 on Nansemond River (p=0.013).

Month	Mean	Min	Max	Median Group	
January	18.35	2.90	43.00	A	B
February	9.45	2.90	23.00	A	B
March	10.19	2.90	23.00	A	B
April	18.99	2.90	93.00		B
May	6.89	2.90	23.00	A	B
June	10.24	2.90	93.00	A	
July	7.49	2.90	43.00	A	B
August	5.09	2.90	15.00	A	B
September	44.18	2.90	460.00	A	B
October	51.14	2.90	460.00	A	B
November	21.51	2.90	93.00	A	B
December	28.05	2.90	93.00	A	B

Table 2.30 Summary of Mood's Median Test on mean monthly *enterococci* at 63-4 on Nansemond River (p=0.001).

Month	Mean	Min	Max	Median Group	
January	23.88	3.60	93.00		B
February	8.73	2.90	43.00	A	B
March	16.84	2.90	93.00	A	B
April	19.89	2.90	43.00		B
May	11.65	2.90	23.00	A	B
June	32.12	2.90	460.00	A	
July	7.02	2.90	43.00	A	
August	5.31	2.90	23.00	A	
September	15.49	2.90	43.00	A	B
October	106.55	2.90	1,100	A	B
November	28.59	2.90	93.00		B
December	42.05	2.90	240.00	A	B

Table 2.31 Summary of Mood's Median Test on mean monthly *enterococci* at 63-5 on Nansemond River (p=0.001).

Month	Mean	Min	Max	Median Group	
January	19.14	2.90	43.00	A	B
February	7.64	2.90	23.00	A	
March	16.88	2.90	75.00	A	B
April	12.79	2.90	43.00		B
May	7.35	2.90	23.00	A	B
June	8.00	2.90	43.00	A	B
July	9.38	2.90	43.00	A	B
August	6.16	2.90	23.00	A	B
September	22.33	2.90	93.00	A	B
October	28.27	2.90	93.00	A	B
November	19.62	3.60	43.00	A	B
December	32.05	2.90	150.00	A	B

Table 2.32 Summary of Mood's Median Test on mean monthly *enterococci* at 63-6 on Nansemond River (p=0.014).

Month	Mean	Min	Max	Median Group	
January	26.20	3.60	150.00	A	B
February	8.02	2.90	23.00	A	B
March	19.15	2.90	43.00	A	B
April	24.62	2.90	93.00		B
May	15.66	2.90	75.00	A	B
June	11.01	2.90	93.00	A	
July	9.94	2.90	43.00	A	B
August	8.38	2.90	23.00	A	B
September	24.79	2.90	93.00	A	B
October	68.93	2.90	460.00		B
November	50.18	3.60	240.00		B
December	48.49	2.90	240.00		B

Table 2.33 Summary of Mood's Median Test on mean monthly *enterococci* at 63-7 on Nansemond River (p=0.018).

Month	Mean	Min	Max	Median Group	
January	21.85	2.90	75.00	A	B
February	8.16	2.90	23.00	A	
March	18.15	2.90	43.00	A	B
April	28.35	9.10	93.00		B
May	15.85	2.90	43.00	A	B
June	11.76	2.90	43.00	A	
July	20.95	2.90	93.00	A	B
August	15.77	2.90	43.00	A	B
September	20.14	3.00	150.00	A	B
October	28.37	2.90	93.00	A	B
November	27.98	2.90	75.00	A	B
December	27.43	2.90	150.00	A	B

Table 2.34 Summary of Mood's Median Test on mean monthly *enterococci* at 63-10 on Nansemond River (p=0.006).

Month	Mean	Min	Max	Median Group	
January	47.41	2.90	240.00	A	B
February	9.01	2.90	39.00	A	
March	32.54	3.00	240.00	A	B
April	58.95	2.90	150.00	A	B
May	35.90	2.90	240.00	A	B
June	34.43	2.90	240.00	A	B
July	31.16	2.90	150.00	A	B
August	27.02	3.00	93.00	A	B
September	34.58	3.60	240.00	A	B
October	73.17	7.20	460.00	A	B
November	50.02	9.10	150.00		B
December	89.67	3.60	460.00	A	B

Table 2.35 Summary of Mood's Median Test on mean monthly *enterococci* at 63-11 on Nansemond River (p=0.044).

Month	Mean	Min	Max	Median Group	
January	114.35	3.60	1,200	A	B
February	14.96	2.90	75.00	A	
March	34.22	2.90	93.00	A	B
April	53.60	23.00	150.00		B
May	34.85	2.90	150.00	A	B
June	103.20	2.90	1,200	A	B
July	45.28	3.60	240.00	A	
August	31.97	2.90	93.00	A	B
September	26.54	2.90	93.00	A	B
October	96.29	3.60	460.00	A	B
November	31.98	3.60	75.00	A	B
December	56.32	2.90	460.00	A	B

3. SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal coliform in the Nansemond River watershed. The source assessment was used as the basis for model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local management agencies. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and nonpoint sections. The representation of the following sources in the model is discussed in section 4.

3.1 Watershed Characterization

The National Land Cover Data (NLCD) produced cooperatively between the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (USEPA) was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project led by four U.S. government agencies: USEPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA). Using 30-meter resolution Landsat 5 Thematic Mapper (TM) satellite images taken between 1990 and 1994, digital land use coverage was developed identifying up to 21 possible land use types. Classification, interpretation, and verification of the land cover dataset involved several data sources when available including: aerial photography; soils data (NRCS 2004a, NRCS 2004b), population and housing density data; state or regional land cover data sets; USGS land use and land cover (LUDA) data; 3-arc second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data. Approximate acreages and land use proportions for each impaired segment are given in Table 3.1 and shown in Figure 3.1.

Table 3.1 Contributing land use area for the Nansemond River watershed.

Impairment	**Land use**									
	Barren/ Transitional	**Commercial**	**Forest**	**HIR**	**Livestock Access (LAX)**	**LIR/ Urban Grass**	**Pasture Hay**	**RowCrop**	**Water**	**Wetland**
	acres	acres	acres	acres	acres	acres	acres	acres	acres	acres
Shingle Creek	85.82	383.09	807.66	782.06	600.12	487.88	1,124.87	5.58	6,426.07	3.24
Nansemond River (Upper)	578.05	2,314.76	16,070.41	1,200.49	75.22	2,950.53	6,478.75	11,264.12	1,424.61	16,039.52
Nansemond River (Lake Meade Dam)	578.05	2,623.99	16,439.14	1,200.49	85.62	3,041.15	7,049.71	11,975.98	1,619.82	19,679.18
Nansemond River and Tributaries	1,416.26	3,300.09	34,547.16	1,228.95	229.56	4,663.47	16,138.07	23,552.04	6,592.12	29,600.65

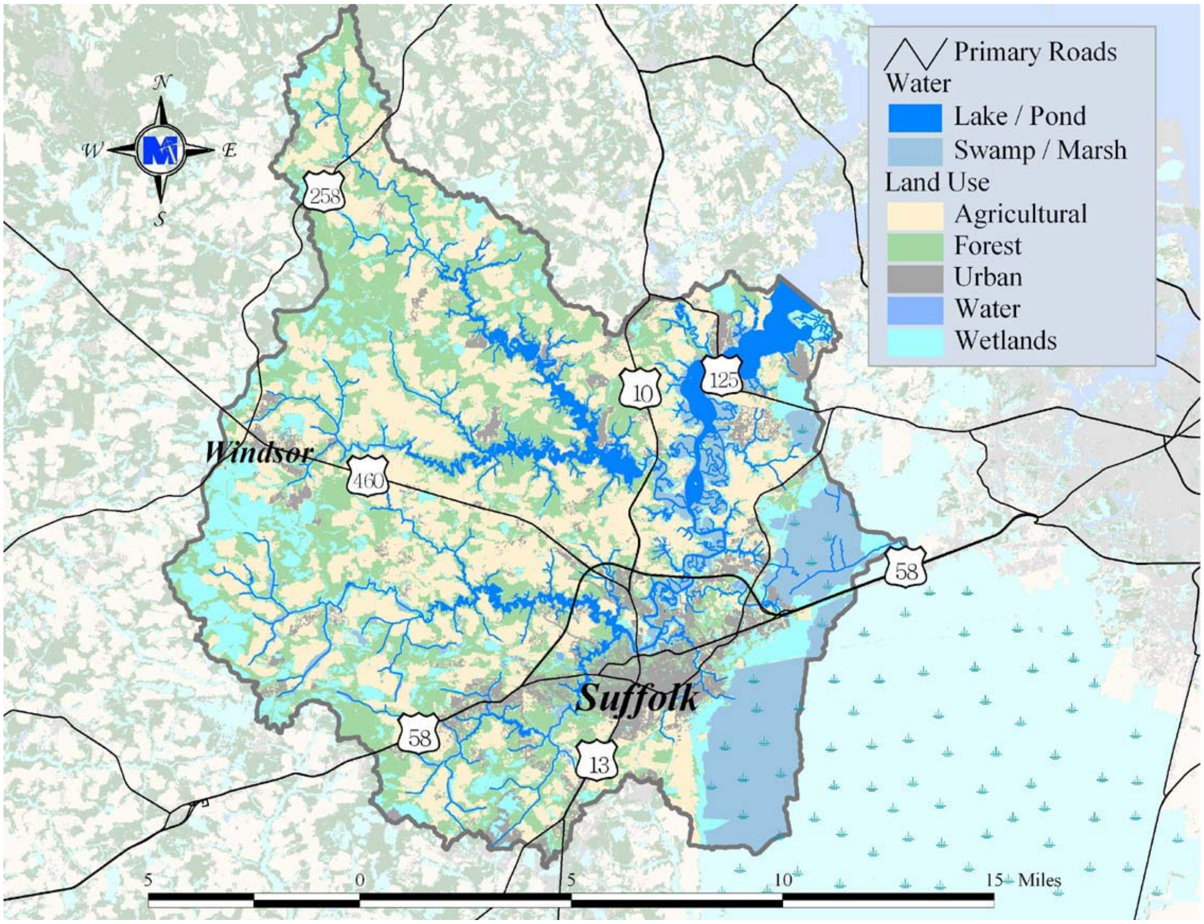

Figure 3.1 Land uses in the Nansemond River watershed.

The estimated human population within the Nansemond River drainage area currently is 47,605. Among Virginia counties and cities, Suffolk City ranks 3rd for the production of peanuts, 2nd for cotton and 10th for soybeans (Virginia Agricultural Statistics, 2002). Isle of Wight County ranks 4th for the production of peanuts, 3rd for cotton and 5th for soybeans (Virginia Agricultural Statistics, 2002). Suffolk City is home to 531 species of wildlife including 54 types of mammals (*e.g.,* beaver, raccoon, and white - tailed deer) and 218 types of birds (*e.g.,* wood duck, wild turkey) (VDGIF, 2006). Isle of Wight County has 420 species of wildlife including 48 types of mammals and 203 types of birds (VDGIF, 2006).

For the period from 1948 to 2004, the Nansemond River watershed received an average annual precipitation of approximately 47.89 inches, with 56% of the precipitation occurring during the May through October growing season (SERCC, 2006). Average annual snowfall is 7.2 inches, with the highest snowfall occurring during January (SERCC, 2006). Average annual daily temperature is 59.1 ºF. The highest average daily temperature of 88.1 ºF occurs in July, while the lowest average daily temperature of 29.9 ºF occurs in January (SERCC, 2006).

3.2 Assessment of Point Sources

Twenty-two (22) point sources are permitted in the Nansemond River watershed through the Virginia Pollutant Discharge Elimination System (VPDES). Figure 3.2 shows the locations permitted for fecal control. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml. Currently, these permitted discharges are expected not to exceed the 126 cfu/100ml *E. coli* standard. One method for achieving this goal is chlorination. Chlorine is added to the discharge stream at levels intended to kill off any pathogens. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. If the concentration is high enough, pathogen concentrations (including fecal coliform concentrations) are considered reduced to acceptable levels. Typically, if minimum TRC levels are met, bacteria concentrations are reduced to levels well below the standard.

Table 3.3 summarizes data from Confined Animal Feeding Operations (CAFO) facilities along with the streams that receive potential runoff from these facilities. These ten facilities are permitted through the Virginia Pollution Abatement (VPA) progoram, and do not have direct discharges to waterways but runoff from the area could contain fecal coliform and *E. coli* bacteria.

Table 3.2 Summary of VPDES, General, and MS4 permitted point sources in the Nansemond River watershed.

Facility Name[1]	Locality/Receiving Waters[2]	Permit No	Design Flow (MGD)	Permitted For Fecal Control	Data Modeled within Time Period
Portsmouth City	UT to Pitch Kettle Creek/Lake Meade	VA0006301	0.775	No	1/1999-1/2006
Suffolk City Mt. Zion Elementary School	UT to Sadler Pond to Lake Meade	VA0021709	0.0045	Yes	7/1998-10/2001
IOW County Windsor Elem School	Ditch to Ennis Pond to Lake Prince	VA0027138	0.0108	Yes	10/1994-7/2000
IOW County Windsor High School	Ditch to Ennis Pond to Lake Prince	VA0027146	0.0096	Yes	10/1994-7/2000
Ciba Specialty Chem	UT to Nansemond River	VA0058254	0.11	No	1/1999-1/2006
Windsor Apartments	Ditch to Antioch Swamp	VA0069302	0.008	Yes	8/1995-11/2000
Twin Ponds Mobile Home Park	Ditch to Antioch Swamp	VA0073952	0.03	No	10/1995-12/2000
City of Suffolk	Nansemond River	VA0076473	0.138	No	1/1999-1/2006
Parker Oil Company Suffolk	UT to Lake Kilby	VA0086134	0.065	Yes	1/1999-present
SE Public Service Authority	Nansemond River	VA0090034	0.0065	No	7/1999-1/2006
Commercial Ready Mix Products Inc - Suffolk	Ditch to UT to Beamon Pond	VAG110062	0.01506	No	1/1991-2/2006
TCS Materials - Suffolk	UT to Speights Run	VAG110102	0.01506	No	1/1991-2/2006
Capital Concrete Incorporated - Windsor	Ennis Pond	VAG110172	0.01506	No	1/1991-2/2006
Commercial Ready Mix Products Inc - Suffolk	Ditch to UT to Beamon Pond	VAG113004	0.01506	No	1/1991-2/2006
TCS Materials - Suffolk	UT to Speights Run	VAG113034	0.01506	No	1/1991-2/2006
Titan Virginia Ready Mix LLC - Suffolk	Lake Kilby	VAG113042	0.01506	No	1/1991-2/2006
Kirk Lumber Company Incorporated	Private Pond to West Branch Reservoir	VAG250031	--	No	1/1991-2/2006
Kirk Lumber Company Incorporated	Private Pond to West Branch Reservoir	VAG253024	--	No	1/1991-2/2006

[1]IOW = Isle of Wight
[2]UT = unnamed tributary

Table 3.2 Summary of VPDES, General, and MS4 permitted point sources in the Nansemond River watershed (cont.).

Facility Name	Locality/Receiving Waters	Permit No	Design Flow (MGD)	Permitted For Fecal Control	Data Modeled within Time Period
Brown, Edward M. Residence	Corrowaugh Swamp	VAG403000	0.00045	Yes	1/1991-2/2006
B and B Car Wash	Suffolk MS4	VAG750127	0.005	No	1/1991-2/2006
Burris Borrow Pit	Lake Kilby	VAG840002	--	No	1/1991-2/2006
Burris Borrow Pit	Lake Kilby	VAG843030	--	No	1/1991-2/2006
Suffolk MS4 (Municipal Separate Storm Sewer System)	West Branch Reservoir, Nansemond River	VAR040044	--	Yes	No Data

Table 3.3 Summary of VPA permits in the Nansemond River watershed.

Facility Name	Locality/Receiving Waters[1]	Permit No	Type	Permitted For Fecal Control	Active Time Period
3 Gs Hog Farm	Suffolk	VPG100126	CAFO	Yes	11/1992-present
Savage Farm	Suffolk	VPG100165	CAFO	Yes	11/2004-present
John H. Byrum Farms	Windsor	VPG150005	CAFO	Yes	5/1995-11/2004
Savage Farm	Suffolk	VPG150041/ (VPG100165)	CAFO	Yes	6/2000-11/2004
Cleve E. and Gregory M. Wood	UT to Ennis Pond to Lake Prince	VPG250001	Poultry	No	2/2001-10/2004
Indika Farms Incorporated	Ditch to UT to Lake Prince	VPG250004	Poultry	Yes	12/2000-10/2004
Residence	Ditch to Lake Prince	VPG250009	Poultry	No	12/2000-1/2006
Farm Residence	Ditch to Lake Burnt Mills	VPG250010	Poultry	No	12/2000-7/2005
Pat J. Cotturone Farm	Shingle Creek	VPG250066	Poultry	Yes	12/2000-present
Vernon, Ray & Linda Edwards Farm	UT to Cahoon Creek	VPG250068	Poultry	Yes	10/2001-present

[1]UT = unnamed tributary

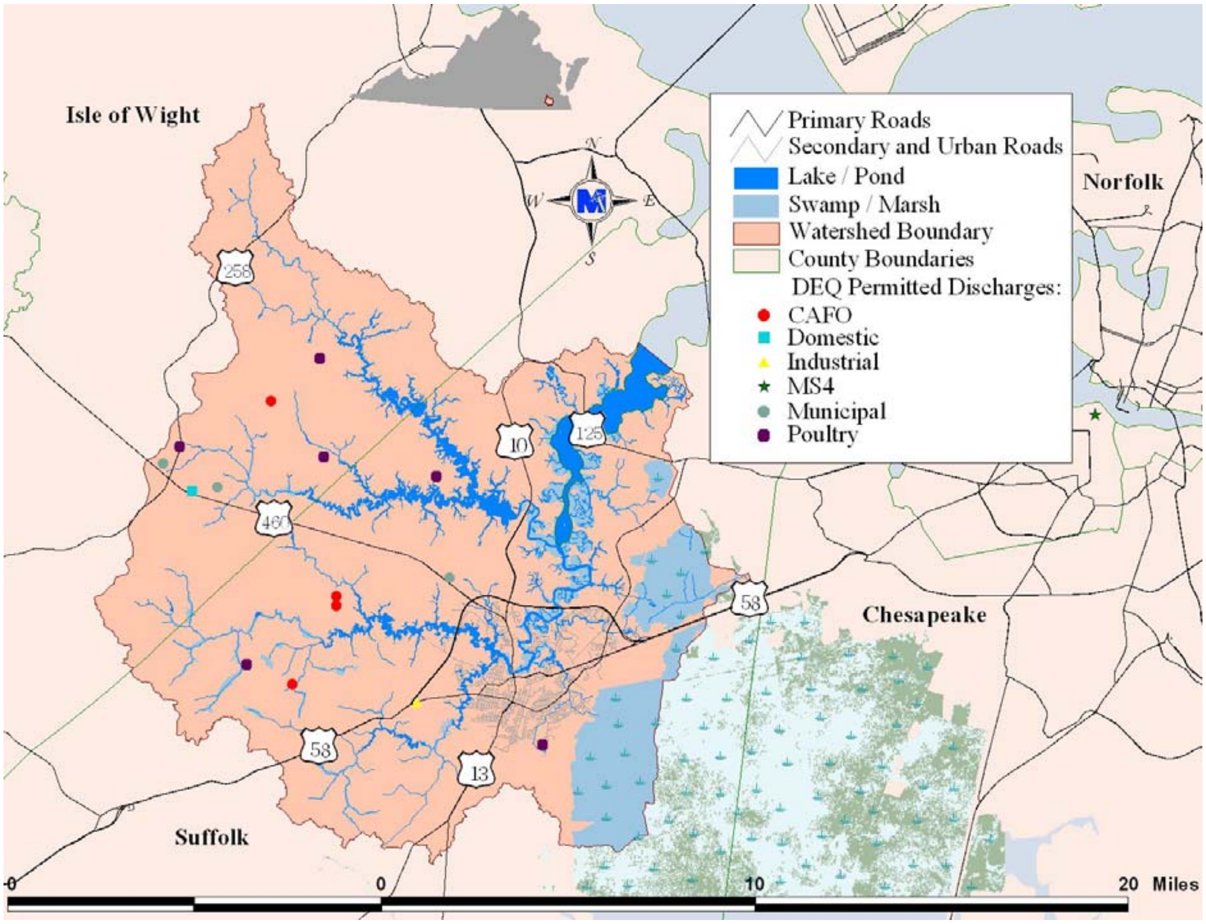

Figure 3.2 Location of VPDES permits for fecal control in the Nansemond River watershed.

3.3 Assessment of Nonpoint Sources

In the Nansemond River watershed, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources include residential sewage treatment systems, land application of waste (dairy and swine), livestock, wildlife, and pets. MapTech previously collected samples of fecal coliform sources (*i.e.,* wildlife, livestock, pets, and human waste) and enumerated the density of fecal coliform bacteria to support the modeling process. Where appropriate, spatial distribution of sources was also determined.

3.3.1 Private Residential Sewage Treatment

In the U.S. Census questionnaires, housing occupants were asked which type of sewage disposal existed. Houses can be connected to a public sanitary sewer, a septic tank, or a cesspool, or the sewage is disposed of in some other way. The Census category "Other Means" includes the houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category are assumed to be disposing of sewage through the use of a straight pipe (direct stream outfall). Population, housing units, and type of sewage treatment from U.S. Census Bureau were calculated using GIS (Table 3.4).

Sanitary sewers are piping systems designed to collect wastewater from individual homes and businesses and carry it to a wastewater treatment plant. Sewer systems are designed to carry a specific "peak flow" volume of wastewater to the treatment plant. Within this design parameter, sanitary collection systems are not expected to overflow, surcharge or otherwise release sewage before their waste load is successfully delivered to the wastewater treatment plant. When the flow of wastewater exceeds the design capacity, the collection system will "back up" and sewage discharges through the nearest escape location. These discharges into the environment are called overflows. Overflows have been observed in the Nansemond River watershed. Wastewater can also enter the environment through exfiltration caused by line cracks, joint gaps, or breaks in the piping system.

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and a drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal coliform to surface waters.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation, the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A survey of septic pump-out contractors performed by MapTech showed that failures were more likely to occur in the winter-spring months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard.

MapTech sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 ml (VADEQ and VADCR, 2000). An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

Table 3.4 Human population, housing units, houses on sanitary sewer, septic systems, and other sewage disposal systems for 2006 in the Nansemond River watershed.

Impaired Segment	Population	Housing Units	Sanitary Sewer	Septic Systems	Other *
Shingle Creek	10,938	4,498	3,792	545	160
Nansemond River (Upper)	34,819	13,923	9,459	4,220	244
Nansemond River (Lake Meade Dam)	38,940	15,274	9,648	5,349	277
Nansemond River and Tributaries	47,605	18,696	10,016	8,302	378

* Houses with sewage disposal systems other than sanitary sewer and septic systems.

3.3.2 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the Nansemond River watershed and were the only pets considered in this analysis. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was previously measured. Fecal coliform density for dogs and cats was measured from samples collected throughout Virginia by MapTech. A summary of the data collected is given in Table 3.5. Table 3.6 lists the domestic animal populations for the impairment.

Table 3.5 Domestic animal population density, waste load, and fecal coliform density.

Type	Population Density (an/house)	Waste load (g/an-day)	FC Density (cfu/g)
Dog	0.534	450	480,000
Cat	0.598	19.4	9

Table 3.6 Estimated domestic animal populations in the Nansemond River watershed for 2006.

Impaired Segment	Dogs	Cats
Shingle Creek	2,402	2,690
Nansemond River (Upper)	7,435	8,326
Nansemond River (Lake Meade Dam)	8,156	9,134
Nansemond River and Tributaries	9,984	11,180

3.3.3 Livestock

The predominant types of livestock in the Nansemond River watershed are swine, dairy and beef cattle although all types of livestock identified were considered in modeling the watershed. Operations range from small to large in size, including several Confined Animal Feeding Operations (CAFOs) permitted under Virginia Pollution Abatement (VPA) regulations. Table 3.3 gives a summary of these permitted operations in the drainage area of impaired streams in the Nansemond River watershed. Table 3.7 gives a summary of current livestock populations in the Nansemond River watershed. Animal populations were based on estimations from Virginia Agricultural Statistics (Virginia Agricultural Statistics, 2002) and were verified via communication with the Peanut Soil and Water Conservation District (PSWCD).

Table 3.7 Livestock populations in the Nansemond River watershed for 2006.

Impairment	Beef	Beef Calves	Dairy Milker	Dairy Dry	Dairy Calves	Hogs	Horses	Sheep
Shingle Creek	65	62	0	0	0	84	36	2
Nansemond River (Upper)	329	112	125	62	63	871	472	32
Nansemond River (Lake Meade Dam)	353	139	125	62	63	971	514	35
Nansemond River and Tributaries	1,045	783	134	67	67	8,358	1,078	60

Values of fecal coliform density of livestock sources were based on sampling performed by MapTech (MapTech, 1999a). Reported manure production rates for livestock were taken from American Society of Agricultural Engineers (1998). A summary of fecal coliform density values and manure production rates is presented in Table 3.8.

Table 3.8 Average fecal coliform densities and waste loads associated with livestock.

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)	Waste Storage Die-off factor
Beef stocker (850 lb)	51.0	101,000	NA
Beef calf (350 lb)	21.0	101,000	NA
Dairy milker (1,400 lb)	120.4	271,329	0.5
Dairy heifer (850 lb)	70.0	271,329	0.25
Dairy calf (350 lb)	29.0	271,329	0.5
Hog (135 lb)	11.3	400,000	0.8
Horse (1,000 lb)	51.0	94,000	NA
Sheep (60 lb)	2.4	43,000	NA
Poultry (broiler; 1 lb)	0.17	586,000	0.5

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.,* pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Based on discussions with the PSWCD, it was concluded that dairy milkers and dairy calves are confined 100% of the time. Table 3.9 shows the average percentage of collected livestock waste that is applied throughout the year. Half of the poultry litter is transported out the watershed and the other half is applied to cropland and pasture. Second, grazing livestock deposit manure directly on the land where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage-ways or streams.

Table 3.9 Average percentage of collected livestock waste applied throughout year.

Month	Applied % of Total			
	Dairy	Beef and Horse[1]	Swine	Poultry
January	1.50	0	0	0
February	1.75	0	0	0
March	17.00	0	20.0	12.5
April	17.00	0	20.0	12.5
May	17.00	0	20.0	0
June	1.75	0	0	0
July	1.75	0	0	0
August	1.75	0	0	0
September	5.00	0	0	0
October	17.00	0	20.0	12.5
November	17.00	0	20.0	12.5
December	1.50	0	0	0

[1]Beef cattle and horse waste is not typically collected in this watershed.

Most livestock were expected to deposit some portion of waste on land areas. The percentage of time spent on pasture for dairy and beef cattle was verified by the PSWCD (Tables 3.10 and 3.11). Beef stockers, beef calves, horses and sheep were assumed to be in pasture 100% of the time, with some beef stockers having direct access to streams.

Based on discussions with the PSWCD, it was concluded that replacement (dry) dairy cattle are confined half the day and in pasture during the other half; however, they do not have access to streams or wetlands (Table 3.10).

Table 3.10 Average time replacement (dry) dairy cattle spend in different areas per day.

Month	Pasture (hr)	Stream Access (hr)	Confinement (hr)
January	12	0	12
February	12	0	12
March	12	0	12
April	12	0	12
May	12	0	12
June	12	0	12
July	12	0	12
August	12	0	12
September	12	0	12
October	12	0	12
November	12	0	12
December	12	0	12

Based on discussions with the PSWCD, it was concluded that beef cattle were expected to make small (0.5 hours a day) fecal contributions through direct deposition to streams in areas where the water flowed freely. In areas with stream fencing BMPs in place, or areas with large amounts of standing or slowly moving water (*i.e.,* swamps) it was concluded that direct deposition was minimal to non-existent. For areas where direct deposition by cattle is assumed, the average amount of time spent by beef cattle in stream access areas (*i.e.*, within 50 feet of the stream) for each month is given in Table 3.11.

Table 3.11 Average time beef cows spend in pasture and stream access areas per day.

Month	Pasture (hr)	Stream Access (hr)
January	23.5	0.5
February	23.5	0.5
March	23.5	0.5
April	23.5	0.5
May	23.5	0.5
June	23.5	0.5
July	23.5	0.5
August	23.5	0.5
September	23.5	0.5
October	23.5	0.5
November	23.5	0.5
December	23.5	0.5

3.3.4 Wildlife

The predominant wildlife species in the Nansemond River watershed were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, source sampling, and site visits. Population densities were calculated from data provided by VDGIF and FWS, and are listed in Table 3.12 (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; Raftovich, 2004; Rose and Cranford, 1987). The numbers of animals estimated to be in the Nansemond River watershed are reported in Table 3.13. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (USDA Forest Service, 1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996, and Yagow, 1999b). Table 3.14 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on sampling of wildlife scat performed by MapTech. The only value that was not obtained from MapTech sampling in the watershed was for beaver. The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999a). Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in Table 3.15.

Table 3.12 Wildlife population densities for the Nansemond River watershed.

Deer (an/ac of habitat)	Turkey (an/ac of habitat)	Goose (an/ac of habitat)	Duck (an/ac of habitat)	Muskrat (an/ac of habitat)	Raccoon (an/ac of habitat)	Beaver (an/mi of stream)
0.0224	0.0044	0.0072	0.0225	1.2986	0.0303	4.8

Table 3.13 Wildlife populations in the Nansemond River watershed.

Impairment	Deer	Turkey	Goose	Duck	Muskrat	Raccoon	Beaver
Shingle Creek	208	47	69	217	12,525	414	26
Nansemond River (Upper)	1,173	226	146	457	26,361	1,716	356
Nansemond River (Lake Meade Dam)	1,296	253	188	588	33,925	1,979	437
Nansemond River and Tributaries	2,436	458	294	918	53,008	3,458	781

Table 3.14 Wildlife fecal production rates and habitat.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	Primary = region within 600 ft of perennial streams Secondary = region between 601 and 7,920 ft from perennial streams Infrequent/Seldom = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	100	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Beaver[1]	200	Primary = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) Infrequent/Seldom = rest of the watershed area
Deer	772	Primary = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land Secondary = low density residential, medium density residential Infrequent/Seldom = remaining landuse areas
Turkey[2]	320	Primary = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land Secondary = cropland, pasture Infrequent/Seldom = remaining landuse areas
Goose[3]	225	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Mallard (Duck)	150	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area

1 Beaver waste load was calculated as twice that of muskrat, based on field observations.
2 Waste load for domestic turkey (ASAE, 1998).
3 Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003).

Table 3.15 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife.

Animal Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access Areas (%)
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Deer	380,000	5
Turkey	1,332	5
Goose	250,000	50
Duck	3,500	75

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of the TMDL in the Nansemond River watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. There are six basic steps in the development and use of a water quality model: model selection, source assessment, selection of a representative modeling period, model calibration, model validation, and model simulation.

Model selection involves identifying an approved model that is capable of simulating the pollutants of interest with the available data. Source assessment involves identifying and quantifying the potential sources of pollutants in the watershed. Selection of a representative period involves the identification of a time period that accounts for critical conditions associated with all potential sources within the watershed. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Validation is the process of comparing modeled data to observed data during a period other than that used for calibration, with the intent of assessing the capability of the model in hydrologic conditions other than those used during calibration. During validation, no adjustments are made to model parameters. Once a suitable model is constructed, the model is then used to predict the effects of current loadings and potential management practices on water quality. In this section, the selection of modeling tools, source assessment, selection of a representative period, calibration/validation, and model application are discussed.

4.1 Modeling Framework Selection

The Nansemond River watershed contains a broad range of hydrologic systems, and thus requires a very robust and versatile modeling platform. The upstream areas are riverine segments with the streamflow influenced by multiple dams, while downstream segments are tidally influenced and contain more swampland.

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions in riverine and estuarine areas. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climate, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed.

4.1.1 Modeling Free Flowing Impairments

The HSPF model simulates a watershed by dividing it up into a network of stream segments (referred to in the model as RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various land uses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

4.1.2 Modeling Tidal Impairments

The Steady State Tidal Prism Model, which is currently used by VADEQ for modeling tidally impacted waterbodies, was implemented within the HSPF framework to model tidally influenced impairments (shellfish and recreational) in conjunction with upstream free-flowing impairments. MapTech's implementation of the Tidal Prism Model uses the same basic principal of a control volume with ebb and flood tides based on monitored tide data and bathymetry. However, die-off and mixing are controlled within HSPF. This results in a time series of concentration within the impacted waterbody. Allocations can then be determined based directly on the 90th percentile or geometric mean standard.

4.2 Model Setup

Daily precipitation data was available within the Nansemond River watershed at the Suffolk Lake Kilby NCDC Coop station #448192. Missing values were filled first with daily precipitation from the Driver 4NE NCDC Coop station #442504, then with data from the Holland 1E NCDC Coop station #444044. The resulting daily precipitation was disaggregated into hourly precipitation using the distribution from the Williamsburg 2N NCDC Coop station #449151.

To adequately represent the spatial variation in the watershed, the Nansemond River drainage area was divided into 7 subwatersheds (Figure 4.1) for the purpose of modeling hydrology and water quality. The rationale for choosing these subwatersheds was based on the availability of water quality data, the impairment lengths and locations, and the limitations of the HSPF model. Water quality data (*i.e.,* fecal coliform concentrations) are available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with selected monitoring stations, since output from the model can only be obtained at the modeled subwatershed outlets (Figure 4.1). The total drainage area of Shingle Creek is subwatershed 5. The Nansemond River (Upper) impairment is located in subwatershed 2; the total drainage area is subwatersheds 1 and 2. The Nansemond River (Lake Meade Dam) impairment is located in subwatersheds 2 and 3; the total drainage area is subwatersheds 1, 2 and 3. The final impairment (Nansemond River and Tributaries) spans subwatersheds 2, 3, 4, 5, and 7; the total drainage area is all subwatersheds (Figure 4.1).

Subwatersheds 2, 3, 4, 5, and 7 contain the estuarine or tidally influenced streams. Subwatersheds 1 and 6 are free flowing streams with the exception of man-made dams. The Lake Meade drainage area is represented by subwatershed 1. It includes Lake Meade, Lake Kilby, Lake Cohoon and Speights Run, as well as the dams that dictate the streamflow. The Western Branch Reservoir drainage area is represented by subwatershed

6. The area includes the Western Branch Reservoir, Lake Prince, and Lake Burnt Mills and the corresponding dams. All of these structures are not equipped with gates so the discharge of the dam is regulated only by stream depth, meaning when the stream is at a certain depth, discharge over the dam will occur. All the waterbodies in subwatershed 1 and 6 are not impaired for the primary contact recreational or the shellfish harvest use.

In an effort to standardize modeling efforts across the state, VADEQ has required that fecal bacteria models be run at a 1-hour time-step. The HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. These modeling constraints as well as the desire to maintain a spatial distribution of watershed characteristics and associated parameters were considered in the delineation of subwatersheds. The spatial division of the watersheds allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watersheds.

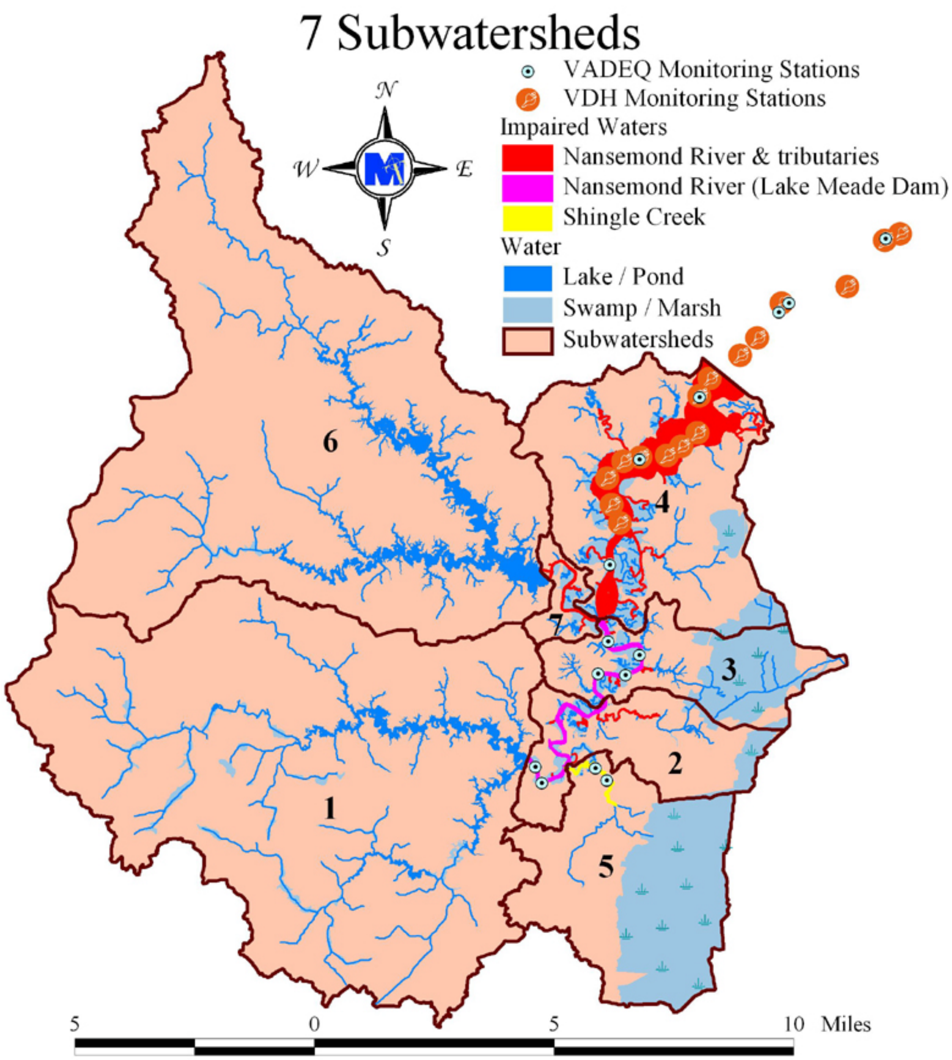

Figure 4.1 Subwatersheds delineated for modeling and location of VADEQ water quality monitoring stations and VDH water quality monitoring stations.

Using aerial photographs and MRLC 15 land use types were identified in the watersheds. The 15 land use types were consolidated into ten categories based on similarities in hydrologic and waste application/production features (Table 4.1). Within each subwatershed, up to the ten land use types were represented. Each land use had parameters associated with it that described the hydrology of the area (*e.g.,* average slope length) and the behavior of pollutants (*e.g.,* fecal coliform accumulation rate). Table 4.2 shows the consolidated land use types and the area existing in the impairments. These land use types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). Impervious areas in the watershed are represented in four IMPLND types, while there are ten PERLND types, each with parameters describing a particular land use. Some IMPLND and PERLND parameters (*e.g.,* slope length) vary with the particular subwatershed in which they are located. Others vary with season (*e.g.,* upper zone storage) to account for plant growth, die-off, and removal.

Table 4.1 Consolidation of MRLC land use categories for the Nansemond River watershed modeling.

TMDL Land use Categories	Pervious / Impervious (%)	Land use Classifications (MRLC Class No. where applicable)
Barren/Trans	Pervious (80%) Impervious (20%)	Transitional (33) Quarries/Strip Mines/Gravel Pits (32)
Commercial	Pervious (60%) Impervious (40%)	Commercial/Industrial/Transportation (23)
Row Crop	Pervious (100%)	Row Crops (82)
Forest	Pervious (100%)	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)
Livestock Access (LAX)	Pervious (100%)	Pasture/Hay (81) near streams
Pasture/Hay	Pervious (100%)	Pasture/Hay (81)
HIR	Pervious (80%) Impervious (20%)	High Intensity Residential (HIR) (22)
LIR/UrbanGrass	Pervious (90%) Impervious (10%)	Low Intensity Residential (LIR) (21) Urban/Recreational Grasses (85)
Water	Pervious (100%)	Open Water (11)
Wetlands	Pervious (100%)	Woody Wetlands (91) Emergent Herbaceous Wetlands (92)

Table 4.2 Contributing land use area for the impairments in the Nansemond River watershed.

Impairment	Contributing Subwatersheds	Land use: Barren/ Transitional	Commercial	Forest	HIR	LAX
		acres	acres	acres	acres	acres
Shingle Creek	5	85.82	383.09	807.66	782.06	600.12
Nansemond River (Upper)	1, 2, 5	578.05	2,314.76	16,070.41	1,200.49	75.22
Nansemond River (Lake Meade Dam)	1, 2, 3, 5	578.05	2,623.99	16,439.14	1,200.49	85.62
Nansemond River and Tributaries	All (1-7)	1,416.26	3,300.09	34,547.16	1,228.95	229.56

Table 4.2 Contributing land use area for the impairments in the Nansemond River watershed (cont.).

Impairment	Contributing Subwatersheds	Land use: LIR/ Urban Grass	Pasture Hay	Row Crop	Water	Wetland	Total
		acres	acres	acres	acres	acres	acres
Shingle Creek	5	487.88	1,124.87	5.58	6,426.07	3.24	10,706.39
Nansemond River (Upper)	1, 2, 5	2,950.53	6,478.75	11,264.12	1,424.61	16,039.52	58,396.46
Nansemond River (Lake Meade Dam)	1, 2, 3, 5	3,041.15	7,049.71	11,975.98	1,619.82	19,679.18	64,293.13
Nansemond River and Tributaries	All (1-7)	4,663.47	16,138.07	23,552.04	6,592.12	29,600.65	121,268.37

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter (fecal matter deposited directly on land), die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

4.3 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.,* stream geometry and resistance to flow). This data are entered into HSPF via the Hydraulic Function Tables (F-tables). The F-tables developed consist of four columns: depth (ft), area (ac), volume (ac-ft), and outflow (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. The area listed is the surface area of the flow in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second.

In order to develop the entries for the F-tables, a combination of the NRCS Regional Hydraulic Geometry Curves (NRCS, 2006) and Digital Elevation Models (DEM) was used. The NRCS has developed an empirical formula for estimating stream top width, cross-sectional area, average depth, and flow rate, all as functions of the drainage area. Estimates were obtained at the outlet of each subwatershed. Using the NRCS equations, an entry was developed in the F-table that represented a bank-full situation for the streams. However, the F-table is supposed to cover the floodplains. The floodplain information was obtained from the Digital Elevation Modal (DEM). A profile perpendicular to the channel was generated showing the floodplain height with distance for each subwatershed outlet (Figure 4.2). Consecutive entries to the F-table are generated by estimating the volume of water and surface area in the reach at incremental depths taken from the profile. An example is shown in Figure 4.2.

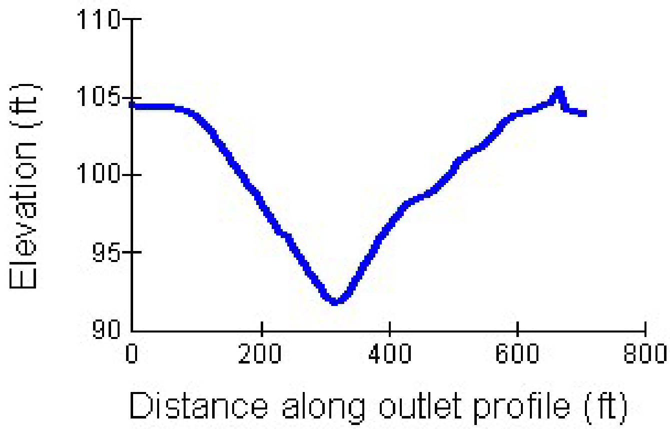

Figure 4.2 Stream profile representation in HSPF.

Conveyance was used to facilitate the calculation of discharge in the reach with values for resistance to flow (Manning's *n*) assigned based on recommendations by Brater and King (1976) and shown in Table 4.3. The conveyance was calculated for each of the two floodplains and the main channel; these figures were then added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from DEMs and a stream-flow network based on National Hydrography Dataset (NHD) data. The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (in ft^3/s) at a given depth. An example of an F-table used in HSPF is shown in Table 4.4.

Table 4.3 Summary of Manning's roughness coefficients for channel cells*.

Section	Upstream Area (ha)	Manning's *n*
Intermittent stream	18 - 360	0.06
Perennial stream	360 and up	0.05

*Brater and King (1976)

Table 4.4 Example of an "F-table" calculated for the HSPF model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (ft^3/s)
0	0	0	0
0.1	0.6	1.69	0.05
0.17	10.76	4.46	24.26
0.77	10.76	10.44	241.7
7.67	11.84	82.36	11150.2
9.59	13.64	104.21	16167.77
11.99	35.37	186.7	21029.3
14.39	36.12	270.99	38599.01
246.99	108.79	16985.15	17519166
479.6	181.45	50601.57	76135368

4.4 Selection of Representative Modeling Period

Selection of the modeling period was based on availability and quality of data (discharge and water-quality) and the need to represent critical hydrologic conditions. Using these criteria, modeling periods were selected for hydrology calibration and validation, water quality calibration and validation, and modeling of allocation scenarios.

The modeling periods were selected to include the VADEQ assessment period from July 1990 through June 2001 that led to the inclusion of the impaired streams in this TMDL study area on the 1996, 1998, 2002 and 2004 Section 303(d) lists. The fecal concentration data from this period were evaluated to determine the relationship between concentration and the level of flow in the stream. High concentrations of fecal coliform were recorded in all flow regimes, thus it was concluded that the critical, or representative, hydrological condition included a wide range of wet and dry seasons.

In order to select a modeling period representative of the critical hydrological condition from the available data, the mean daily precipitation for each season was calculated for the period 1933 through Fall 2003. This resulted in 69 to 71 observations of precipitation for each season. The mean and variance of these observations were calculated. Next, a candidate period was chosen based on the availability of mean discharge data closest to the fecal coliform assessment period (1/90-2/04). The representative period was chosen from this candidate period such that the mean and variance of each season in the modeled period was not significantly different from the historical data. Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. The results of these analyses are shown in Figures 4.3 and 4.4 and Table 4.5.

The resulting period chosen for hydrologic calibration was 10/1/1997 to 9/30/2002. However, since the data available for hydrologic calibration was available at two different locations, adjustments were made to this time period. As total monthly volume of discharge over the Lake Meade Dam was available starting in January 1998, the period used for hydrologic modeling was 01/1998 to 10/2003 for subwatershed 1. Daily stage measurements were available at the Western Branch Reservoir throughout the entire hydrologic calibration period; therefore, subwatershed 6 was calibrated for hydrology from 10/1/1997 to 9/30/2002.

For hydrologic model validation, the period selected was 10/1/1991 to 9/30/1996. This period was also adjusted to account for the available data at subwatershed 1. Instantaneous discharge values were available once per month at the Lake Meade Dam from 1/4/1991 to 7/7/1995. Starting in August 1995, the stage was measured every Monday, Wednesday and Friday resulting in more data. It was decided that the same type of data be used for calibration and validation, therefore, the validation period used was 1/4/1991 to 7/7/1995. Since daily stage was available for the Western Branch Reservoir the time period used for validation of subwatershed 6 was10/1/1991 to 9/30/1996.

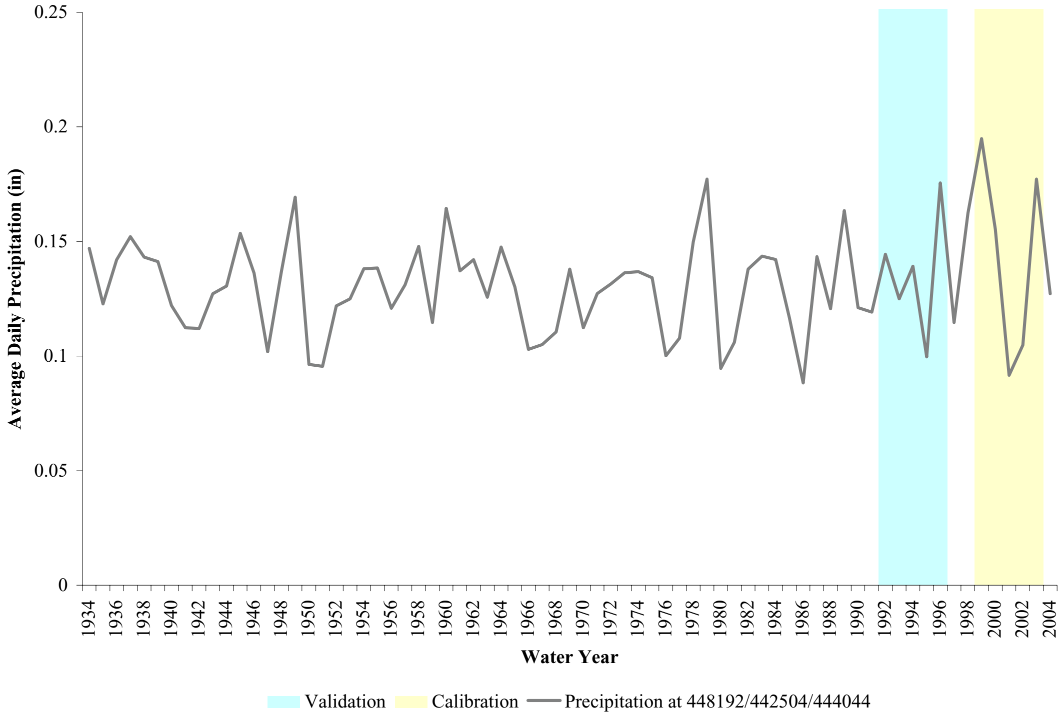

Figure 4.3 Annual Historical Precipitation Data (Stations 448192, 442504, 444044) and representative modeling time periods for the Nansemond River watershed.

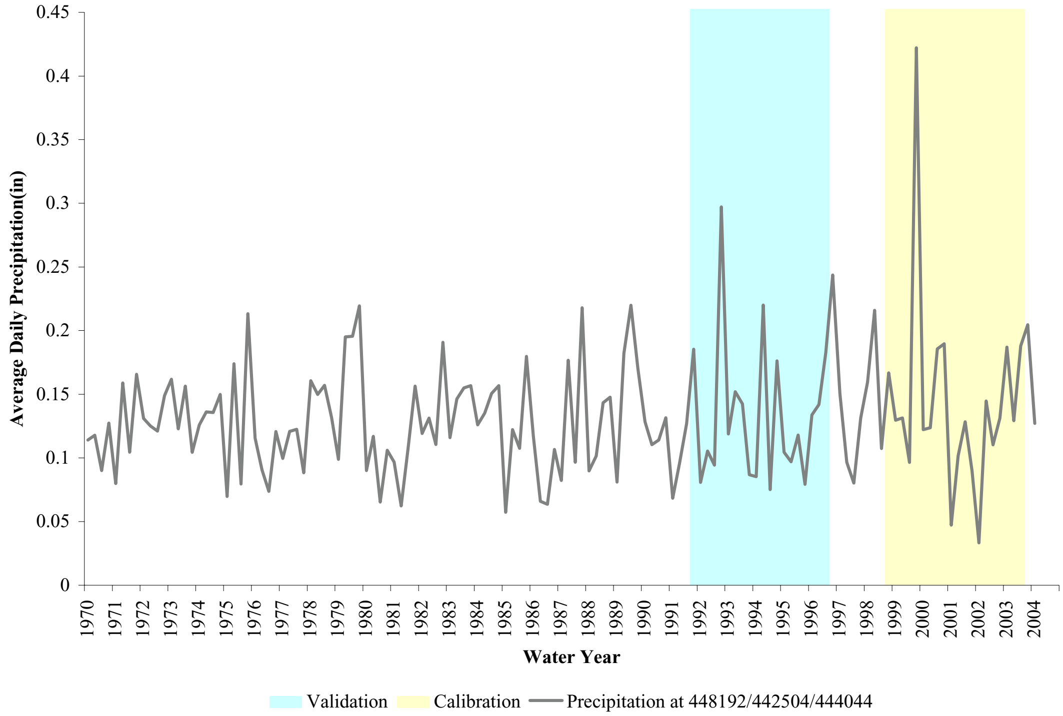

Figure 4.4 Seasonal Precipitation Data (Stations 448192, 442504, 444044) and representative modeling time periods for the Nansemond River watershed.

Table 4.5 Comparison of modeled period to historical records for the Nansemond River watershed.

	Precipitation (448192/442504/444044)[1]			
	Fall	**Winter**	**Summer**	**Spring**
	Historical Record (1933 - 2004)			
Mean	0.104	0.127	0.123	0.170
Variance	0.001	0.001	0.002	0.003
	Calibration and Validation Time Periods (10/97-9/02; 10/91-9/96)			
Mean	0.102	0.143	0.124	0.188
Variance	0.002	0.002	0.001	0.012
	p-values			
Mean	0.433	0.135	0.472	0.304
Variance	0.284	0.209	0.468	0.001

[1]Secondary Station utilized only when Primary Station was off-line.

For water quality modeling, data availability was the governing factor in the choice of calibration, validation, and allocation periods. The period containing the greatest amount of monitored data dispersed over the most stations, and for which the assessment of potential sources was most accurate (10/1/1996 to 9/30/2001), was chosen as the calibration period. This period contained 299 water quality data points. The period from 1/1/1990 to 9/30/1995 was chosen as the validation period, with 195 data points. The period most representative of the watershed (10/1/1997 to 9/30/2002) was chosen as the allocation period to ensure that the critical conditions in the watershed were being simulated during water quality allocations.

4.5 Source Representation

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.,* animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Direct depositions by nocturnal animals were modeled as being deposited from 6:00 PM to 6:00 AM, and direct depositions by diurnal animals were modeled as being deposited from 6:00 AM to 6:00 PM. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.,* population). Depending on the timeframe of the simulation being run, different numbers should be used. Data representing 1999 were used for the water quality calibration period (1996-2001) and data representing 1992 were used for validation period (1989-1994). Data representing 2006 were used for the allocation runs in order to represent current conditions.

4.5.1 Point Sources

Twenty-two (22) point sources are permitted to discharge to waterbodies in the Nansemond River watershed. Seven (7) of these facilities are permitted for fecal control, with known fecal coliform concentrations and design discharges ranging from 0.00045-0.138 MGD (Table 3.2). For calibration and validation condition runs, recorded flow and fecal coliform concentration or Total Residual Chlorine (TRC) levels documented by the VADEQ were used as the input for each permit. The TRC data was related to fecal colifrom concentrations using a regression analysis. The design flow capacity was used for allocation runs. This flow rate was combined with a fecal coliform concentration of 200 cfu/100 ml (when applicable) to ensure that compliance with state water quality standards could be met even if permitted loads were at maximum levels.

Nonpoint sources of pollution that were not driven by runoff (*e.g.*, direct deposition of fecal matter to the the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

4.5.2 Private Residential Sewage Treatment

The number of septic systems in the seven subwatersheds modeled for water quality in the Nansemond River wastershed was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the watersheds to enumerate the septic systems. Each residential land use area was assigned a number of septic systems based on census data. A total of 5,653 septic systems were estimated in the Nansemond River watershed in 1990. During allocation runs, the number of households was projected to 2006 values, based on current growth rates (USCB, 2000) resulting in 8,302 septic systems (Table 4.6).

Table 4.6 Estimated 2006 residential sewage treatment systems in the Nansemond River watershed.

Impaired Segment	Septic Systems	Failing Septic Systems	Uncontrolled Discharges
Shingle Creek	545	157	160
Nansemond River (Upper)	4,220	944	244
Nansemond River (Lake Meade Dam)	5,349	1,033	277
Nansemond River and Tributaries	8,302	1,595	378

4.5.2.1 Failing Septic Systems

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. In accordance with estimates from Raymond B. Reneau, Jr. of the Crop and Soil Environmental Sciences Department at Virginia Tech, a 40% failure rate for systems designed and installed prior to 1964, a 20% failure rate for systems designed and installed between 1964 and 1984, and a 5% failure rate on all systems designed and installed after 1984 was used in development of the TMDL for the Nansemond River watershed. Total septic systems in each category were calculated using U.S. Census Bureau block demographics. The applicable failure rate was multiplied by each total and summed to get the total failing septic systems per subwatershed. The fecal coliform density for septic system effluent was multiplied by the density of people per house to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

4.5.2.2 Uncontrolled Discharges

Uncontrolled discharges were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category “other means” were assumed to be disposing sewage via uncontrolled discharges. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the wasteload for the average size household in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model.

4.5.2.3 Sewer System Overflows

During the model water quality calibration/validation periods (10/1/1989 to 9/30/2001), there were 141 total reported sewer overflows. The majority of sewer overflow event reports contained an estimate of the volume of sewage discharged, so the model included these discharges. It was assumed that additional occurrences of sewer overflows were likely undetected, therefore, a statistical analysis of meteorological events and sewer overflows was performed to determine the flow of water and sewage to surface waters during rainfall events. The concentration of fecal bacteria discharged was considered equivalent to the concentration of septic tank effluent, and the magnitude of the discharge was estimated as the average discharge volume of reported sewer overflow events. As some biodegradation occurs in a septic system, it is felt that the estimate of concentration is conservative.

4.5.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The amount of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers determined for 2006 were used for the allocation runs, while values during 1999 were used for the calibration and 1992 for validation runs. The numbers are based on data provided by VASS and verified by PSWCD. For land-applied waste, the fecal coliform density as-excreted multiplied by the die-off factor was used, while the density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.8). The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

4.5.3.1 Land Application of Collected Manure

Significant collection of livestock manure occurs on various dairy, swine, and poultry farms. For each farm in the drainage area, the average daily waste production per month was calculated using the number of animal units, weight of animal, and waste production rate as reported in section 3.3.3. For dairy farms, the amount of waste collected was based on the total amount of waste produced in confinement, which was calculated based on the portion of time spent in confinement. Finally, values for the percentage of waste collected, based on data provided by SWCD representatives and local stakeholders, were used to calculate the amount of waste available to be spread on pasture and cropland. Swine, poultry, dairy milkers, and dairy calves were assumed to be in confinement 100% of the time with all waste stored. Stored waste was spread equally on pasture and cropland. It was assumed that 100% of land-applied waste is available for transport in surface runoff.

4.5.3.2 Deposition on Land

For cattle, the amount of waste deposited on land per day was a portion of the total waste produced per day. The portion was calculated based on the study entitled "Modeling Cattle Stream Access" conducted by the Biological Systems Engineering Department at Virginia Tech and MapTech, Inc. for the Virginia Department of Conservation and Recreation (VADCR). The portion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Portion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horse and sheep) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture land use type was area-weighted.

4.5.3.3 Direct Deposition to Streams

Beef cattle are the primary source of direct deposition by livestock in the Nansemond River watershed. The amount of waste deposited in streams each day was a portion of the total waste produced per day by cattle. First, the portion of manure deposited in "stream access" areas was calculated based on the "Modeling Cattle Stream Access" study. The portion was calculated as follows:

Portion = (time in stream access areas)/(24 hr)

4.5.4 Biosolids

Investigation of VDH data indicated that no biosolids applications have occurred within the Nansemond River watershed.

4.5.5 Wildlife

For each species of wildlife, a GIS habitat layer was developed based on the habitat descriptions that were obtained (section 3.3.4). An example of one of these layers is shown in Figure 4.5. This layer was used in conjunction with the land use layer and the resulting area was calculated for each land use in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the wasteload, fecal coliform densities, and number of animals for each species.

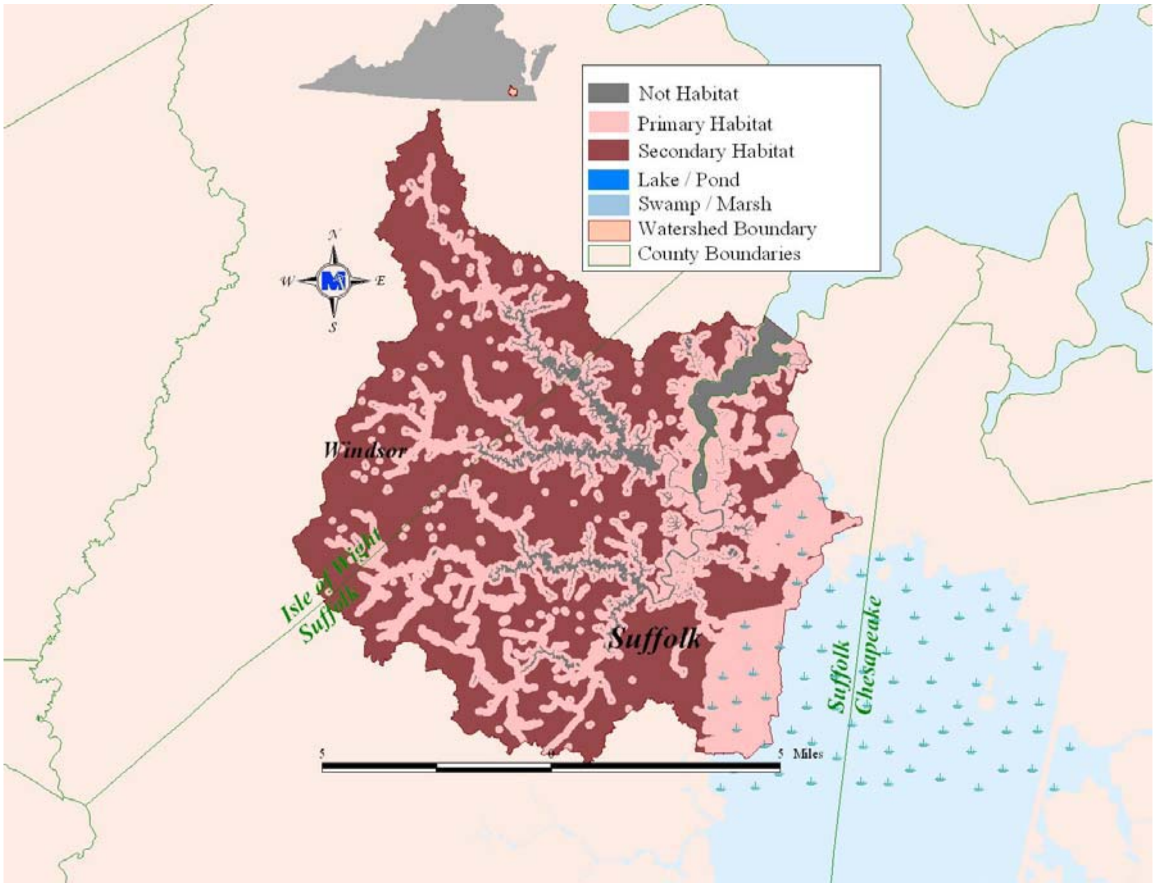

Figure 4.5 Example of raccoon habitat layer in the Nansemond River watershed as developed by MapTech.

Goose and duck wasteloads were not varied based on migration patterns to account for the resident population of birds. No seasonal variation was assumed for the remaining species. For each species, a portion of the total wasteload was considered land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.21). It was estimated that, for all animals other than beaver, 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. No long-term (2006) adjustments were made to wildlife populations, as there was no available data to support such adjustments.

4.5.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), waste load, and fecal coliform density are reported in section 3.3.2. Waste from pets was distributed on residential land uses. The number of households was determined from the 1990 and 2000 Census (USCB, 1990 and USCB, 2000). The number of animals per subwatershed was determined by multiplying the number of households in each subwatershed by the population density of each animal. The amount of fecal coliform deposited daily by pets in each land use segment was calculated by multiplying the waste load, fecal coliform density, and number of animals for both cats and dogs. The waste load was assumed not to vary seasonally. The populations of cats and dogs were projected from 1990 data to 1992, 1999, and 2006 to coincide with modeling periods.

4.6 Sensitivity Analysis

Sensitivity analyses are performed to determine a model's response to changes in certain parameters. This process involves changing a single parameter a certain percentage from a baseline value while holding all other parameters constant. This process is repeated for several parameters in order to gain a complete picture of the model's behavior. The information gained during sensitivity analysis can aid in model calibration, and it can also help to determine the potential effects of uncertainty in parameter estimation. Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.,* seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads). Additional analyses were performed to define the sensitivity of the modeled system to growth or technology changes that impact waste production rates.

4.6.1 Hydrology Sensitivity Analysis

The HSPF parameters adjusted for the hydrologic sensitivity analysis are presented in Table 4.7, with base values for the model runs given. The parameters were adjusted to -50%, -10%, 10%, and 50% of the base value (unless otherwise noted in Table 4.8), and the model was run for water years 1997-2003. Where an increase of 50% exceeded the maximum value for the parameters, the maximum value was used and the parameters increased over the base value were reported. The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliforms from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration) and LZSN (Lower Zone Storage), and to a lesser extent by UZSN (Upper Zone Storage), which governs surface transport, and LZETP (Lower Zone Evapotranspiration), which affects soil moisture. Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows were AGWRC (Groundwater Recession Rate), BASETP (Base Flow Evapotranspiration), LZETP and, to a lesser extent, Infiltration. The responses of these and other hydrologic outputs are reported in Table 4.8.

Table 4.7 HSPF base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
LZSN	Lower Zone Nominal Storage	in	6.62-48.835
INFILT	Soil Infiltration Capacity	in/hr	0.0316-0.1399
AGWRC	Groundwater Recession Rate	---	0.980
BASETP	Base Flow Evapotranspiration	---	0.01
INTFW	Interflow Inflow	---	1.0
DEEPFR	Groundwater Inflow to Deep Recharge	---	0.01
MON-INTERCEP	Monthly Interception Storage Capacity	in	0.0 – 0.20
MON-UZSN	Monthly Upper Zone Nominal Storage	in	0.38 – 4.88
MON-MANNING	Monthly Manning's *n* for Overland Flow	---	0.01 – 0.37
MON-LZETP	Monthly Lower Zone Evapotranspiration	in	0.0 – 0.80

Table 4.8 HSPF Sensitivity analysis results for hydrologic model parameters, model segment 4, Nansemond River.

		Percent Change In							
Model Parameter	**Parameter Change (%)**	**Total Flow**	**High Flows**	**Low Flows**	**Winter Flow Volume**	**Spring Flow Volume**	**Summer Flow Volume**	**Fall Flow Volume**	**Total Storm Volume**
AGWRC[1]	0.85	0.43	4.90	-21.02	4.68	-3.43	5.74	-7.50	3.75
AGWRC[1]	0.92	0.29	2.67	-13.96	4.43	-2.79	3.84	-5.75	2.98
AGWRC[1]	0.96	0.16	1.01	-6.41	2.74	-1.42	1.16	-2.16	1.82
AGWRC[1]	0.999	-10.60	-5.75	-6.40	-12.46	-12.51	-6.31	-12.92	-16.08
BASETP	-50	0.09	-0.10	0.55	-0.18	0.30	0.24	-0.14	0.01
BASETP	-10	0.02	-0.02	0.11	-0.04	0.06	0.05	-0.03	-0.03
BASETP	10	-0.02	0.02	-0.11	0.04	-0.06	-0.05	0.03	0.01
BASETP	50	-0.08	0.11	-0.56	0.19	-0.30	-0.24	0.14	0.25
DEEPFR	-50	0.19	0.07	0.27	0.22	0.22	0.14	0.20	0.20
DEEPFR	-10	0.04	0.01	0.05	0.04	0.04	0.03	0.04	0.04
DEEPFR	10	-0.04	-0.01	-0.05	-0.04	-0.04	-0.03	-0.04	-0.04
DEEPFR	50	-0.19	-0.07	-0.27	-0.22	-0.22	-0.14	-0.20	-0.21
INFILT	-50	-0.29	6.68	-7.90	0.24	-0.83	1.68	-3.19	0.55
INFILT	-10	-0.05	1.00	-1.25	0.05	-0.14	0.29	-0.55	0.13
INFILT	10	0.04	-0.89	1.14	-0.04	0.13	-0.28	0.53	-0.10
INFILT	50	0.19	-3.72	5.04	-0.15	0.48	-1.26	2.43	-0.21
INTFW	-50	0.02	-0.06	-0.21	0.08	-0.01	0.03	-0.01	0.05
INTFW	-10	0.09	-0.23	-0.87	0.29	-0.01	0.13	-0.04	0.22
INTFW	10	0.16	-0.29	-1.40	0.43	0.05	0.23	-0.09	0.40
INTFW	50	0.24	-0.26	-2.03	0.53	0.16	0.37	-0.16	0.62
LZSN	-50	1.94	3.22	-1.77	5.87	1.64	0.01	1.17	3.30
LZSN	-10	0.31	0.49	-0.22	0.82	0.25	0.11	0.13	0.55
LZSN	10	-0.30	-0.42	0.15	-0.72	-0.25	-0.14	-0.14	-0.52
LZSN	50	-1.50	-1.92	0.27	-2.80	-1.59	-0.96	-0.85	-2.46
CEPSC	-50	0.60	-0.22	2.18	-0.10	0.91	0.92	0.44	0.56
CEPSC	-10	0.10	-0.04	0.38	-0.05	0.15	0.18	0.09	0.06
CEPSC	10	-0.10	0.04	-0.36	0.06	-0.14	-0.18	-0.07	-0.07
CEPSC	50	-0.41	0.17	-1.48	0.34	-0.65	-0.81	-0.28	-0.30
LZETP	-50	7.24	5.75	6.66	10.02	5.09	5.60	9.44	7.52
LZETP	-10	0.49	0.34	0.50	0.57	0.38	0.34	0.78	0.48
LZETP	10	-0.54	-0.37	-0.55	-0.63	-0.41	-0.37	-0.84	-0.54
LZETP	50	-5.75	-3.79	-5.88	-6.84	-5.08	-4.26	-7.69	-5.65
NSUR	-50	0.09	1.05	-0.85	-0.06	0.27	0.30	-0.29	0.16
NSUR	-10	0.01	0.16	-0.12	-0.01	0.05	0.05	-0.04	0.03
NSUR	10	-0.01	-0.15	0.11	0.02	-0.04	-0.05	0.04	-0.03
NSUR	50	-0.06	-0.67	0.46	0.08	-0.17	-0.26	0.20	-0.11
UZSN	-50	2.01	5.55	-2.65	-0.14	2.26	3.90	1.04	2.91
UZSN	-10	0.29	0.80	-0.36	0.03	0.29	0.63	0.04	0.43
UZSN	10	-0.26	-0.72	0.30	-0.04	-0.24	-0.59	-0.01	-0.40
UZSN	50	-1.11	-2.99	1.16	-0.24	-0.87	-2.69	0.13	-1.62

[1]Actual parameter value used

4.6.2 Water Quality Parameter Sensitivity Analysis

The model was run during the corresponding water quality calibration time period for the fecal coliform water quality sensitivity analysis. The four HSPF parameters impacting the model's water quality response (Table 4.9) were increased and decreased by amounts that were consistent with the range of values for the parameter. Deviations from the base run are given in Table 4.10. First Order Decay (FSTDEC) and wash off (WSQOP) were the parameters with the greatest influence on the monthly fecal coliform average concentration, although MON-SQOLIM also showed significant potential to influence this value. Graphical depictions of the results of this sensitivity analysis can be seen in Figures 4.6 through 4.9.

Table 4.9 Base parameter values used to determine water quality model response.

Parameter	Description	Units	Base Value
MON-IFLW CONC	Interflow Concentration	---	0-2.7E+04
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	0-2.7E+09
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0-2.8
FSTDEC	In-stream First Order Decay Rate	1/day	1

Table 4.10 Percent change in average monthly fecal coliform geometric mean for the years 1996 - 2001 for Model Segment 4.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly FC Averages for 1996-2001											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	50.03	27.21	39.20	39.80	34.67	47.85	59.95	25.28	36.71	39.58	39.23	35.67
FSTDEC	-10	6.63	4.37	5.95	5.84	5.30	6.65	8.38	4.01	5.62	5.43	5.77	5.17
FSTDEC	10	-5.68	-3.98	-5.31	-5.16	-4.75	-5.79	-7.27	-3.64	-5.03	-4.71	-5.10	-4.58
FSTDEC	50	-22.16	-16.92	-21.80	-21.00	-19.70	-23.04	-28.59	-15.39	-20.72	-18.70	-20.74	-18.79
SQOLIM	10	4.48	14.13	2.66	8.19	9.49	2.87	5.68	2.93	1.24	4.95	4.27	13.03
SQOLIM	25	18.46	29.33	13.99	16.65	35.36	4.54	-33.93	6.17	12.02	9.51	12.27	30.08
SQOLIM	50	-9.64	62.40	21.76	22.99	45.29	16.91	-35.27	9.73	23.73	12.46	18.25	43.19
SQOLIM	100	3.91	67.95	43.01	37.04	53.42	93.61	-40.31	80.98	33.82	12.03	36.81	57.50
WSQOP	-50	-17.25	55.13	14.87	23.98	35.63	4.91	-34.72	20.29	19.46	15.21	18.81	48.36
WSQOP	-10	4.27	8.37	3.76	7.21	5.59	2.89	5.91	3.77	3.06	1.93	6.67	8.23
WSQOP	10	-46.52	-4.78	-5.82	-5.74	-2.37	-2.16	-5.81	-2.48	-6.50	-4.10	0.04	5.73
WSQOP	50	-53.89	-20.79	-24.07	-31.04	-17.36	-11.82	-23.92	-11.22	-17.48	-16.82	-10.80	-23.13
MON-IFLW CONC	-100	-0.01	-0.02	-0.01	-0.01	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01
MON-IFLW CONC	-50	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	-0.01
MON-IFLW CONC	50	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
MON-IFLW CONC	100	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01

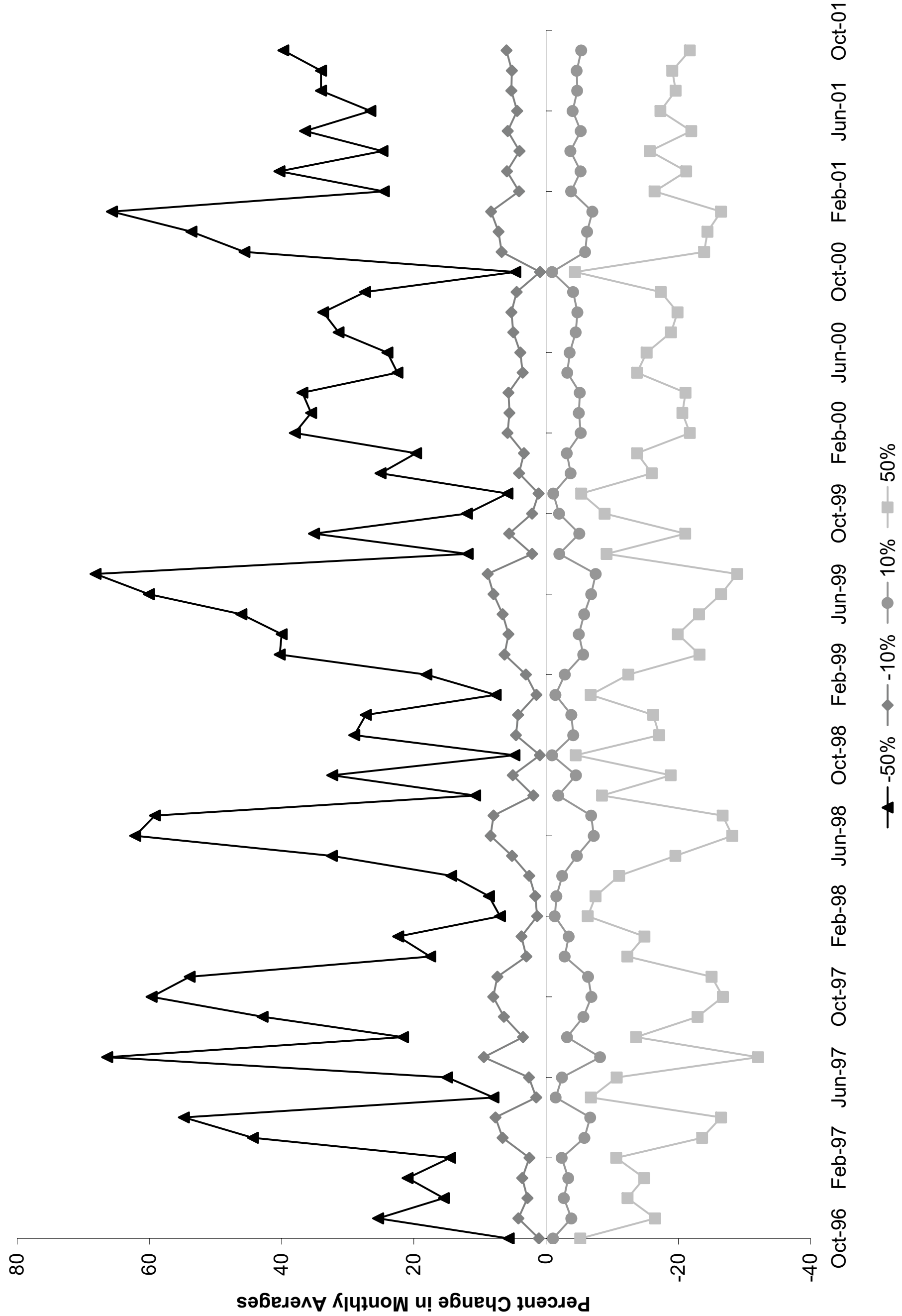

Figure 4.6 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 4, as affected by changes in the in-stream first-order decay rate (FSTDEC).

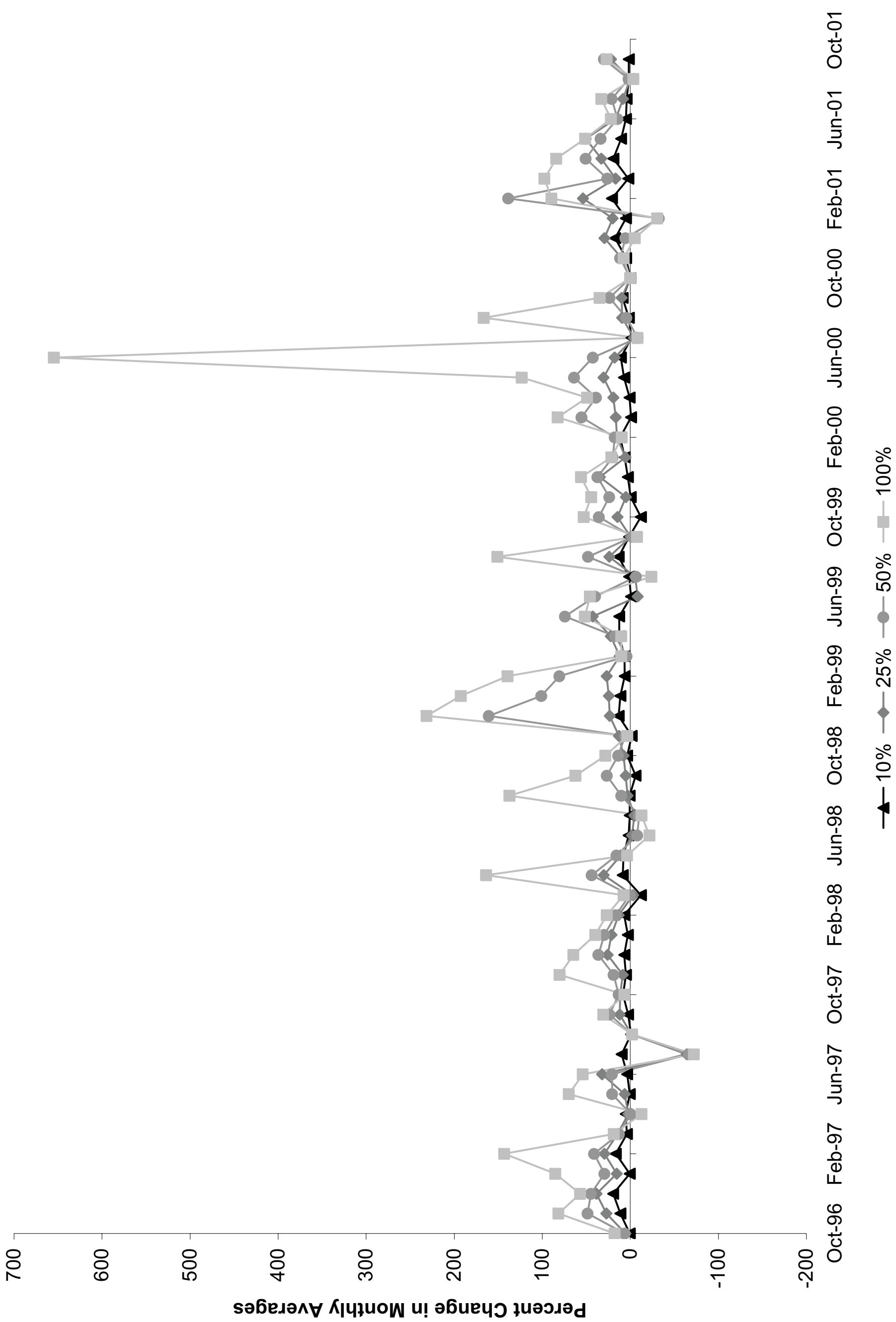

Figure 4.7 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 4, as affected by changes in maximum fecal accumulation on land (MON-SQOLIM).

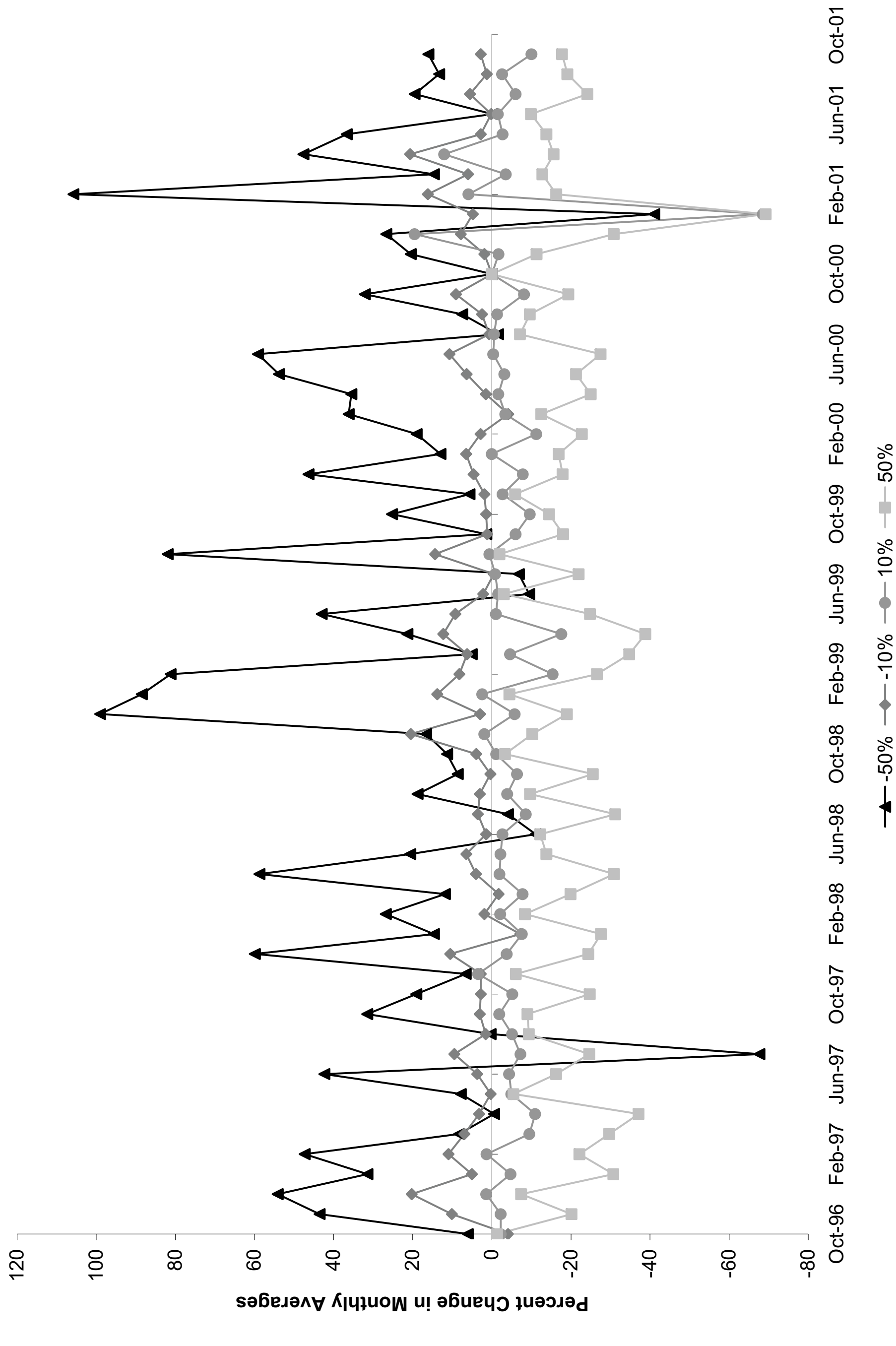

Figure 4.8 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 4, as affected by changes in the wash-off rate from land surfaces (WSQOP).

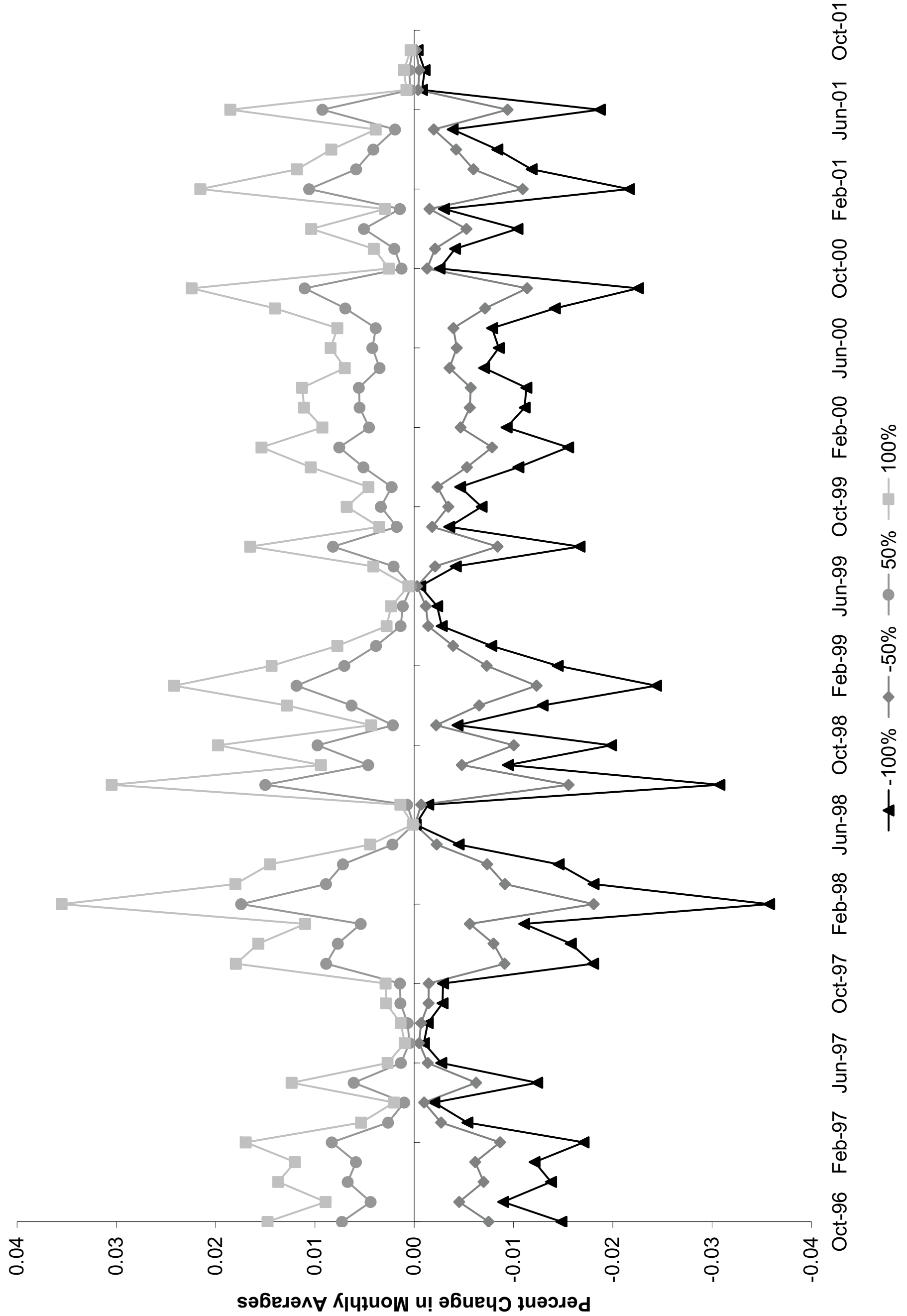

Figure 4.9 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 4, as affected by changes in the concentration of fecal bacteria in interflow (MON-IFLW-CONC).

In addition to analyzing the sensitivity of the model response to changes in water quality transport and die-off parameters, the response of the model to changes in land-based and direct loads was also analyzed. In Figure 4.10 the model predicts a linear relationship between increased fecal coliform concentrations in both land and direct applications, and total load reaching the stream. The magnitude of this relationship differs slightly between land applied and direct loadings; a 100% increase in the land-applied loads results in an increase of approximately 50.6% in stream loads, while a 100% increase in direct loads results in an increase approximately 44.5% for in-stream loads. In contrast, the sensitivity analysis of monthly fecal coliform average concentrations showed that land applied loads had a variable impact, while direct loads had a more consistent impact (Figures 4.11 and 4.12).

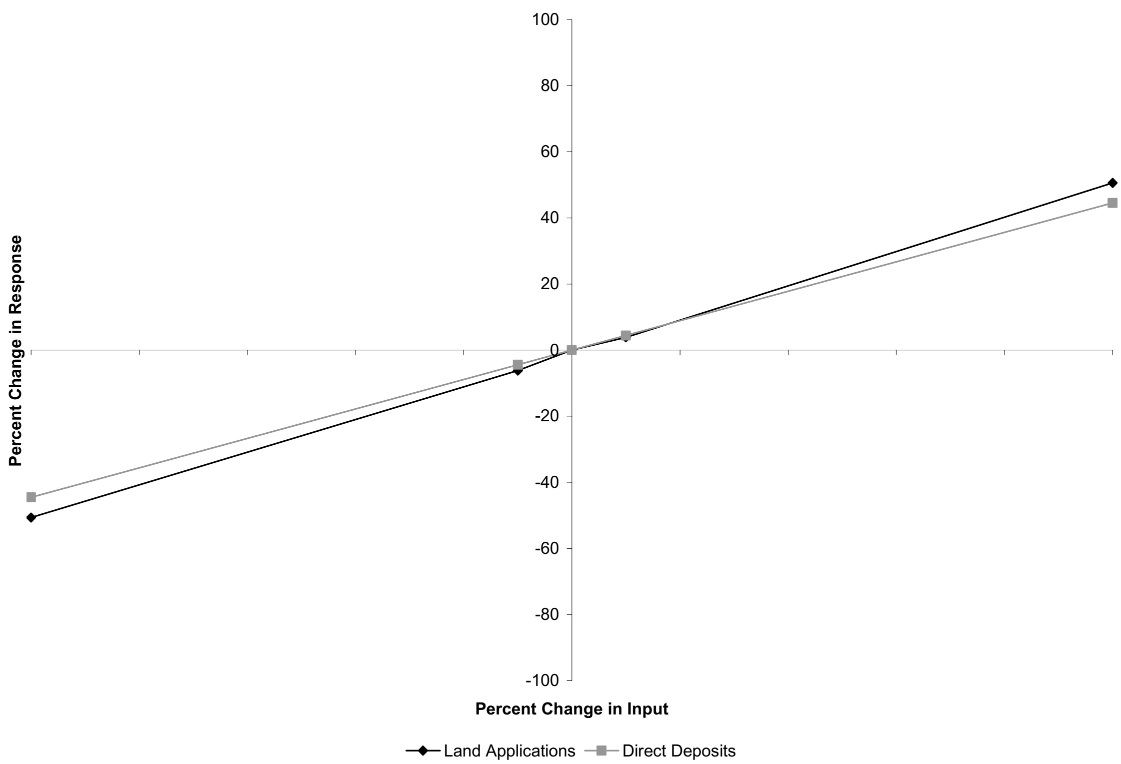

Figure 4.10 Results of total loading sensitivity analysis for segment 4, Nansemond River.

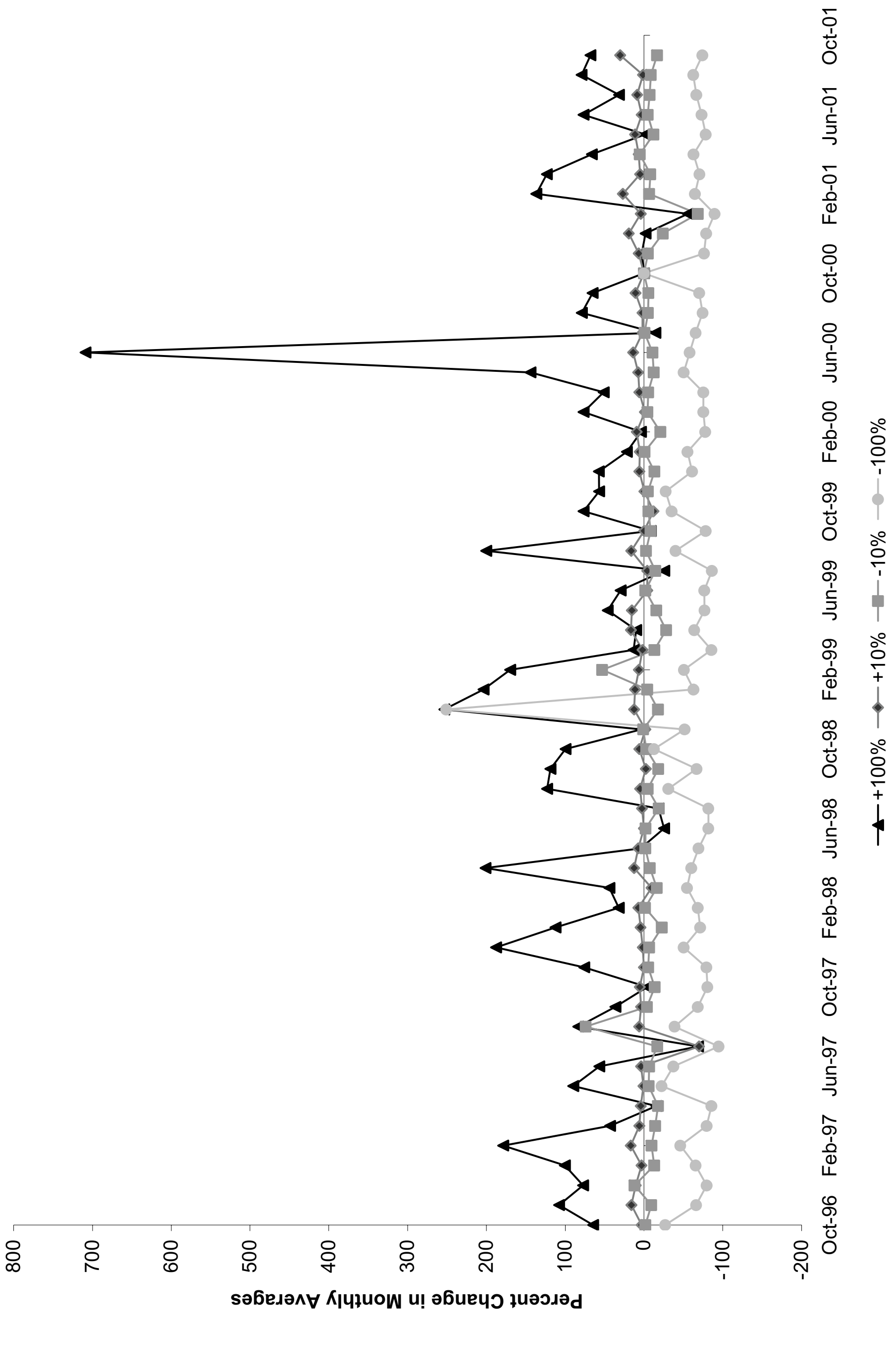

Figure 4.11 Results of sensitivity analysis on monthly geometric-mean concentrations in segment 4, Nansemond River watershed, as affected by changes in land-based loadings.

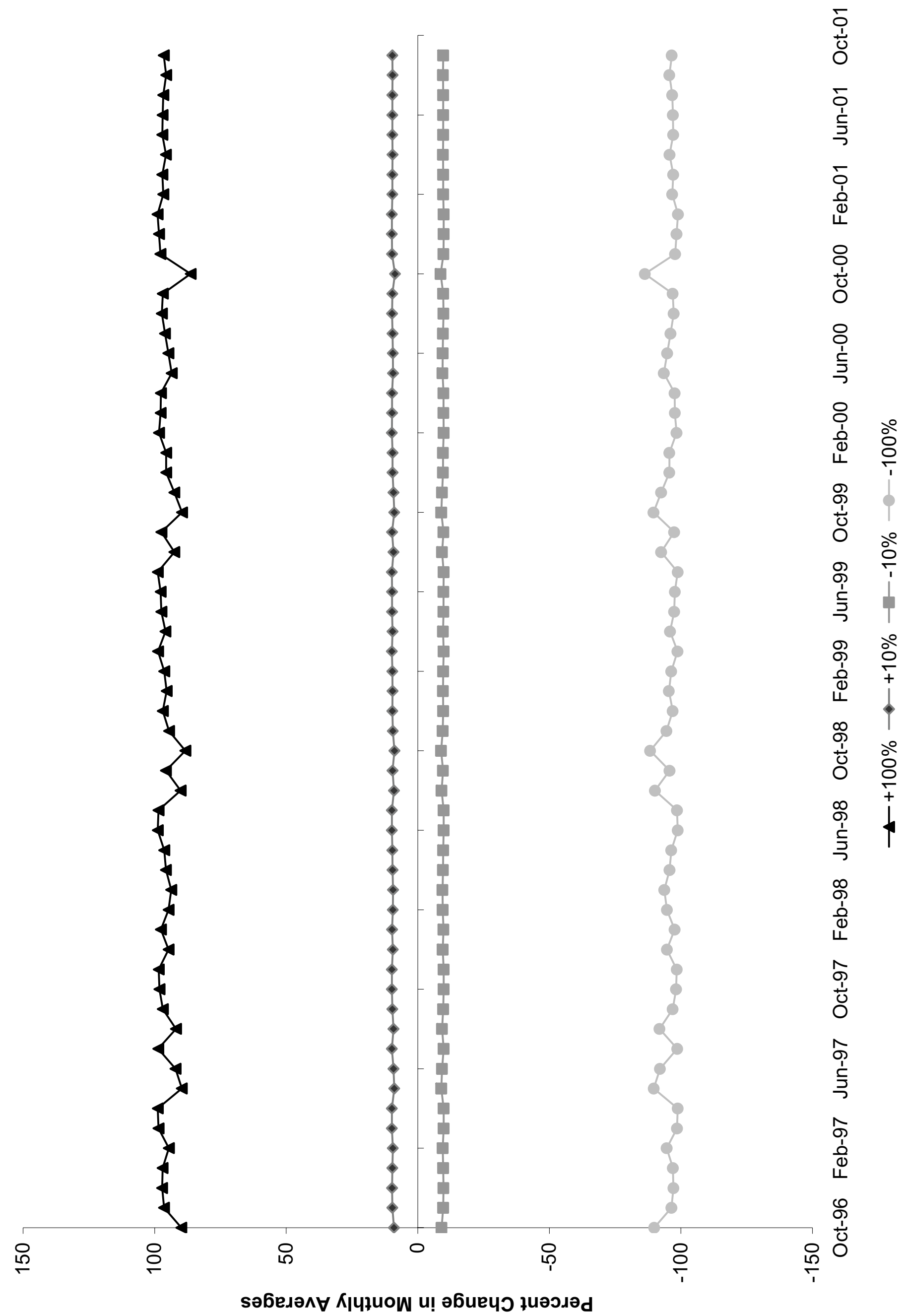

Figure 4.12 Results of sensitivity analysis on monthly geometric-mean concentrations in segment 4, Nansemond River watershed, as affected by changes in loadings from direct nonpoint sources.

4.7 Model Calibration and Validation Processes

Calibration and validation are performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, land use, and topographic data. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

4.7.1 Hydrologic Calibration and Validation

HSPF parameters that can be adjusted during the hydrologic calibration represented: the amount of evapotranspiration from the root zone (LZETP), the recession rates for groundwater (AGWRC) and interflow (IRC), the length of overland flow (SLSUR), the amount of soil moisture storage in the upper zone (UZSN) and lower zone (LZSN), the amount of interception storage (CEPSC), the infiltration capacity (INFILT), the amount of soil water contributing to interflow (INTFW), deep groundwater inflow fraction (DEEPER), baseflow PET (BASETP), forest coverage (FOREST), slope of overland flow plane (LSUR), groundwater recession flow (KVARY), maximum and minimum air temperature affecting PET (PETMAX, PETMIN, respectively), infiltration equation exponent (INFEXP), infiltration capacity ratio (INFILD), active groundwater storage PET (AGWETP), Manning's *n* for overland flow plane (NSUR), interception (RETSC), and the weighting factor for hydraulic routing (KS). Table 4.9 contains the typical range for the above parameters along with the initial estimate and final calibrated value. State variables in the PERLND water (PWAT) section of the User's Control Input (UCI) file were adjusted to reflect initial conditions.

NCDC weather stations Suffolk Lake Kilby (448192), Driver 4NE (442504), and Holland 1E (444044) were used to supply precipitation input for the HSPF model. For the entire modeling period, only daily precipitation values were available, thus daily rainfall values were interpolated to hourly values in order to provide model input on an hourly basis. This interpolation was performed in an HSPF utility called WDMUtil, and is referred to as disaggregation. In this process, a daily rainfall total is divided up into hourly values using a representative distribution scheme. Daily values were disaggregated using a station matching disaggregation scheme. This procedure involved identifying a rain gage reporting hourly data in close proximity to the Nansemond River watershed. In this case, the distribution of rainfall at the station within the watershed was disaggregated based on the precipitation pattern reported at the hourly station Williamsburg 2N (449151).

The model was calibrated for hydrologic accuracy using monthly total volumes over Lake Meade Dam and daily discharge over the Western Branch Reservoir Dam. These streamflow values represented flow from subwatershed 1 and 6, respectively. The data available is described in more detail in section 4.4. The results of the hydrology calibration were acceptable as shown in Figures 4.10 and 4.11. When the observed data showed zero flow HSPF simulated no flow as well.

Table 4.11 Model parameters utilized for hydrologic calibration.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
FOREST	---	0.0 – 0.95	1	1
LZSN	in	2.0 – 15.0	6.62 – 48.835	8.092 – 15.0
INFILT	in/hr	0.001 – 0.50	0.0316 – 0.1399	0.0348 – 0.1539
LSUR	ft	100 – 700	1.0 – 700.0	1.0 – 700.0
SLSUR	---	0.001 – 0.30	0.0031 – 0.0551	0.0031 – 0.0551
KVARY	l/in	0.0 – 5.0	0.0	0.0
AGWRC	l/day	0.85 – 0.999	0.980	0.980
PETMAX	degF	32.0 – 48.0	40.0	40.0
PETMIN	degF	30.0 – 40.0	35.0	35.0
INFEXP	---	1.0 – 3.0	2.0	2.0
INFILD	---	1.0 – 3.0	2.0	2.0
DEEPFR	---	0.0 – 0.50	0.01	0.01 – 0.30
BASETP	---	0.0 – 0.20	0.01	0.20
AGWETP	---	0.0 – 0.20	0.0 – 0.01	0.0 – 0.20
MON-INTERCEP	in	0.01 - 0.40	0.0 – 0.20	0.0 – 0.4
MON-UZSN	in	0.05 – 2.0	0.38 – 4.88	0.47– 2.00
MON-MANNING	---	0.10 – 0.50	0.01 – 0.37	0.01 – 0.37
INTFW	---	1.0 – 10.0	1.0	1.0
IRC	l/day	0.30 – 0.85	0.50	0.50
MON-LZETP	---	0.1 – 0.9	0.0 – 0.80	0.0 – 0.90
RETSC	in	0.0 – 1.0	0.1	0.1
KS	---	0.0 – 0.9	0.5	0.5

Hydrologic validation results are shown in Figures 4.15 and 4.16. These results show that the flow over the dams can be modeled at a different time period and still be accurate.

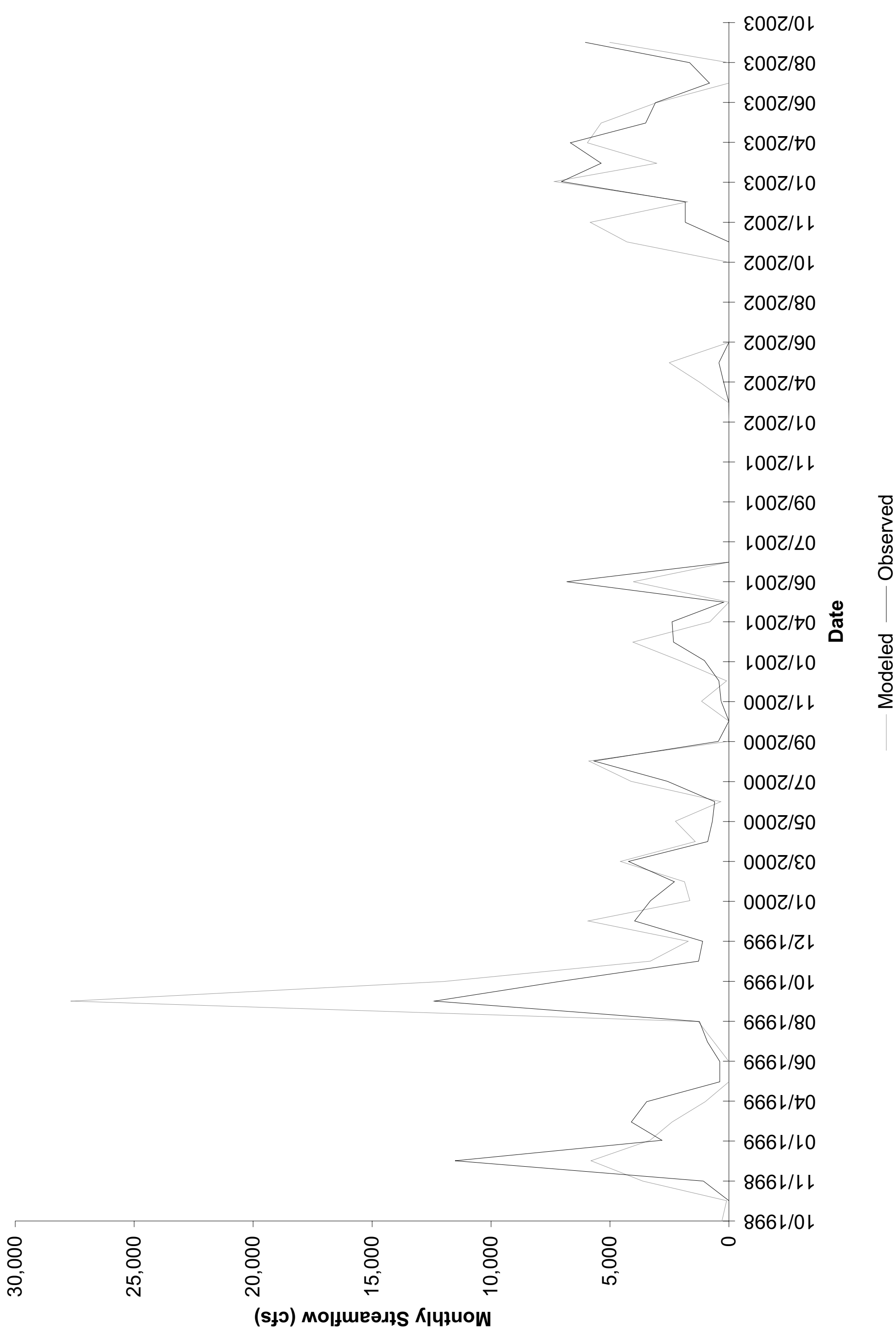

Figure 4.13 Calibration results for period 10/1/1998 through 9/30/2003 at Lake Meade Dam (subwatershed 1).

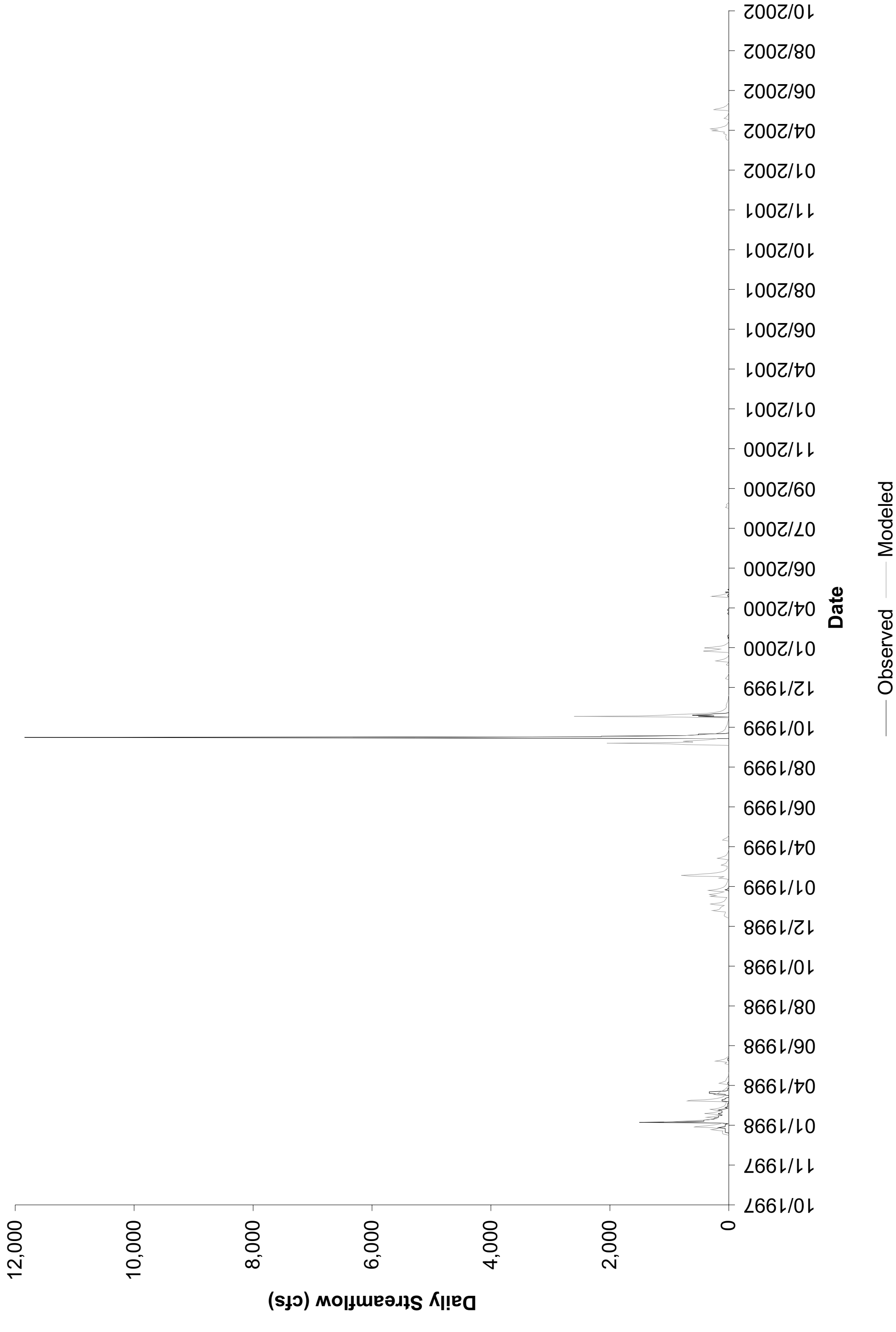

Figure 4.14 Calibration results for period 10/01/97 through 09/30/2002 for Lake Western Branch Dam (subwatershed 6).

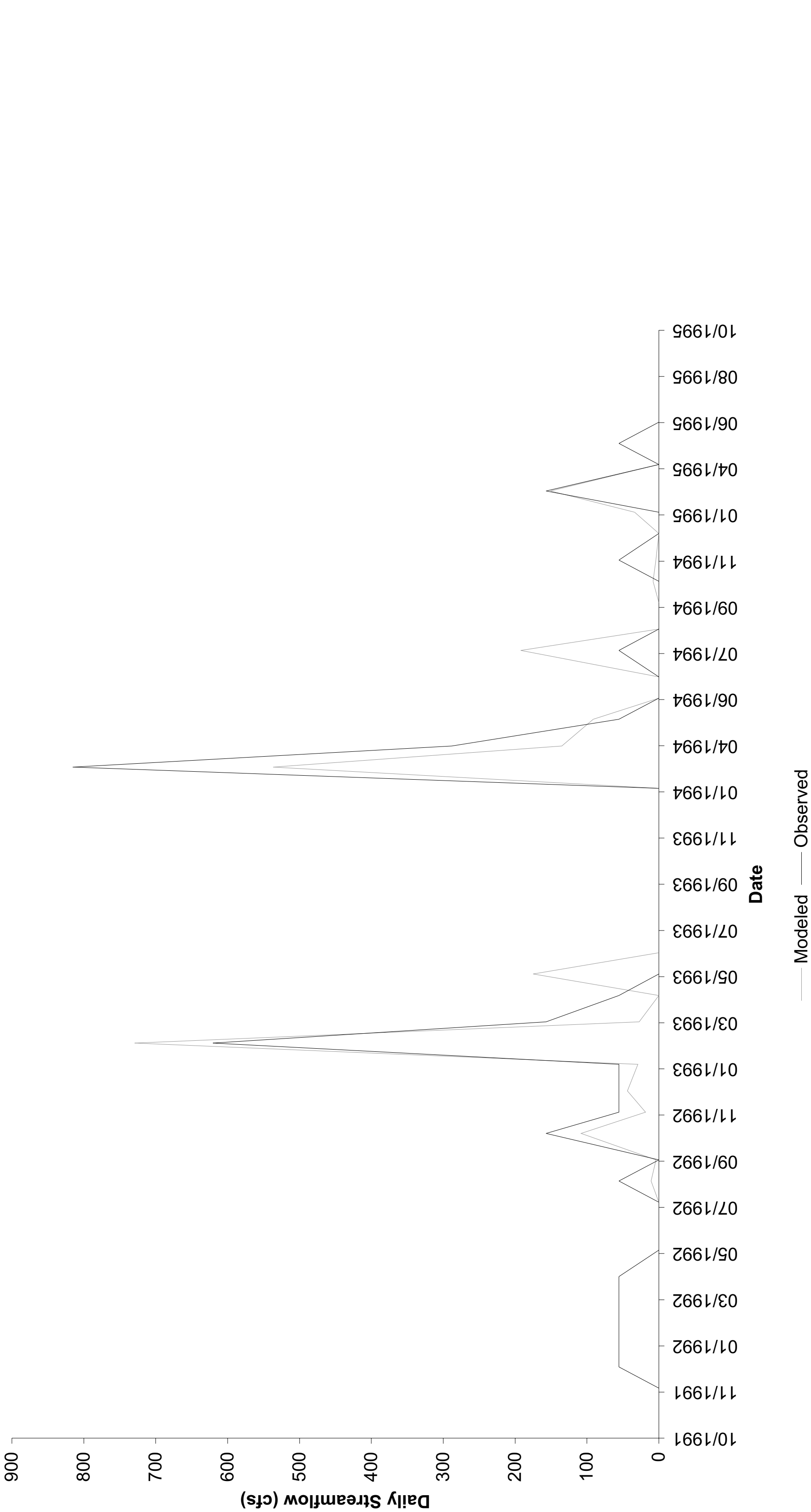

Figure 4.15 Validation results for period 10/1/1991 through 10/1/1995 for Lake Western Branch on the Nansemond River (subwatershed 6).

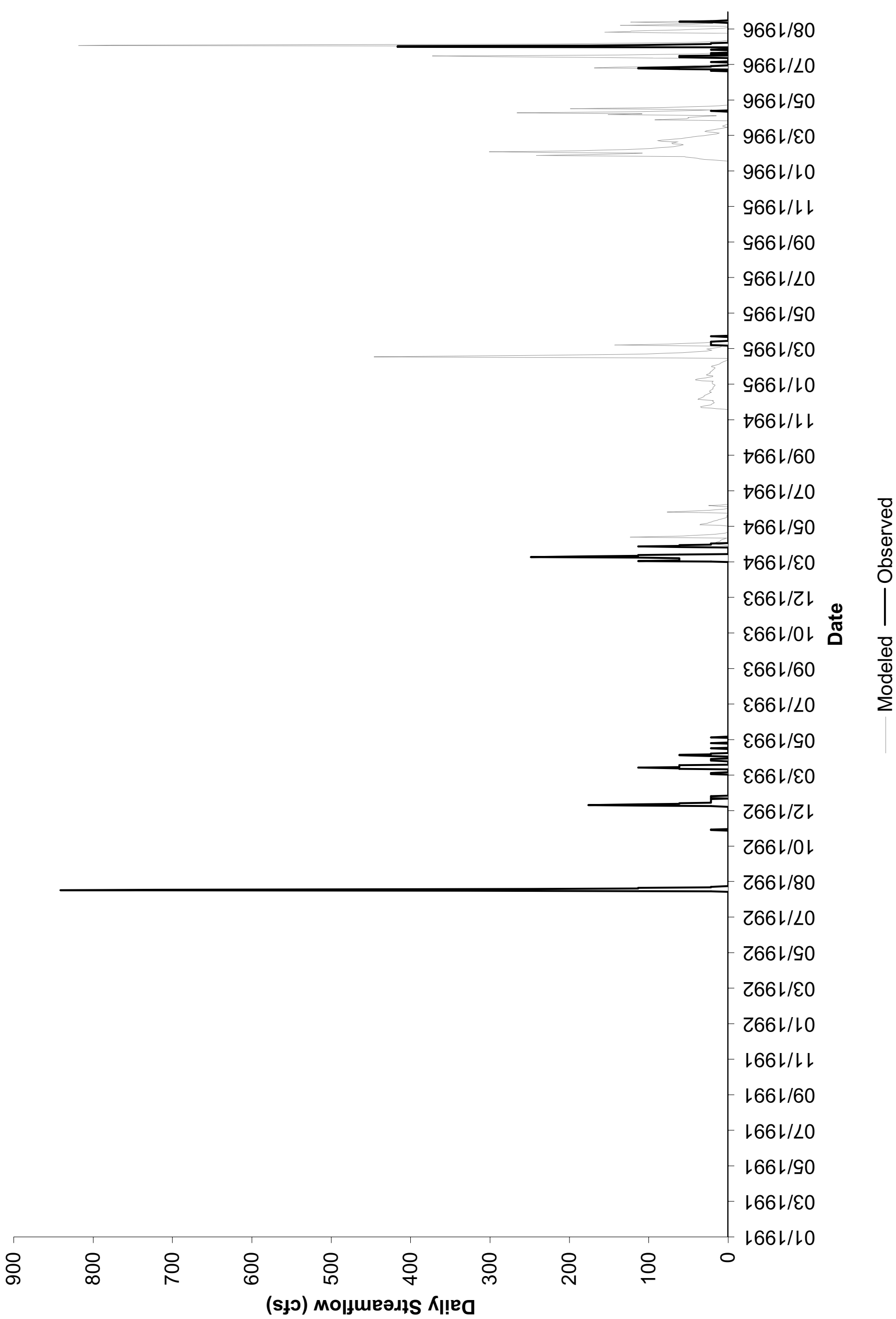

Figure 4.16 Validation results for period 1/1991 through 8/1996 for Lake Meade on the Nansemond River (subwatershed 1).

4.7.2 Water Quality Calibration and Validation

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations (*e.g.,* fecal coliform concentrations) are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters such as fecal coliform concentration. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on regrowth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, of the VADEQ data the maximum values were at times censored at 8,000 cfu/100ml and, at other times, at 16,000 cfu/100ml. The VDH data was censored at 1,200 cfu/100ml. Limited amount of measured data for use in calibration and the practice of censoring both high (over 16,000 cfu/100 ml) and low (under 100 cfu/100 ml) concentrations impede the calibration process.

The water quality calibration was conducted from 10/1/1996 through 9/30/2001. Six parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), monthly maximum accumulation on land (MON-SQOLIM), rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP), and monthly concentration of fecal coliform in interflow (MON-IFLW-CON), temperature correction coefficient for first-order decay (THFST), and the mixing coefficient between tidal inputs and the RCHRES. All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled fecal coliform concentrations was established (Table 4.12). Figures 4.17 through 4.20 show the results of calibration.

Table 4.12 Model parameters utilized for water quality calibration.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0 to 2.7E+09	0.0 to 6.4E+10
WSQOP	in/hr	0.05 – 3.00	0.0 – 2.8	0.0 – 2.8
MON-IFLW-CON	FC/ft^3	0.0E+00 – 1.0E+06	1.0E+05	4.1E+06
FSTDEC	1/day	0.01 – 10.00	1.00	0.02 to 9.0
THFST	---	1.0 – 2.0	1.07	1.0 – 2.0
Mixing coefficient	---	0.3 – 0.7	0.5	0.3 – 0.7

The hydrologic behavior of these areas was characterized by a high degree of interflow, and consequently low degree of direct runoff in these areas, it was necessary to simulate interflow concentrations of fecal coliform in order to match the observed recession curves of pollution plots. In addition to the relatively gradual recession of the falling arm of pollution plots, evidence of bacterial concentrations in shallow sub-surface flow has been detected (Rickmond Engineering, 2002). In order to reflect the variations in loading on land, and to provide for realistic mode response during reduction scenarios, the interflow concentration IOQC, was varied monthly and was computed as a function of loading (MON-ACCUM).

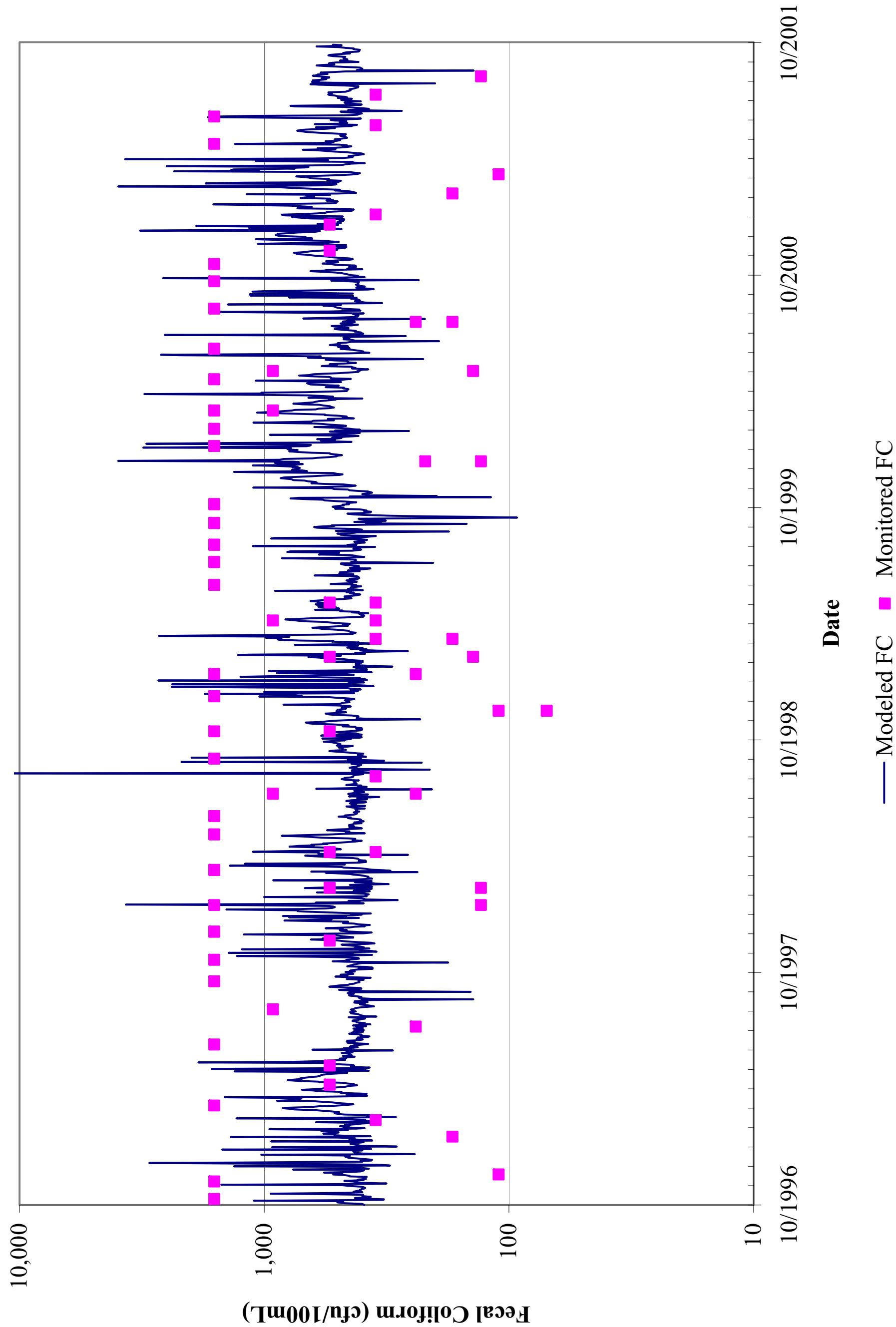

Figure 4.17 Fecal coliform quality calibration results for 10/1/1996 to 9/30/2001 for subwatershed 5, Shingle Creek impairment.

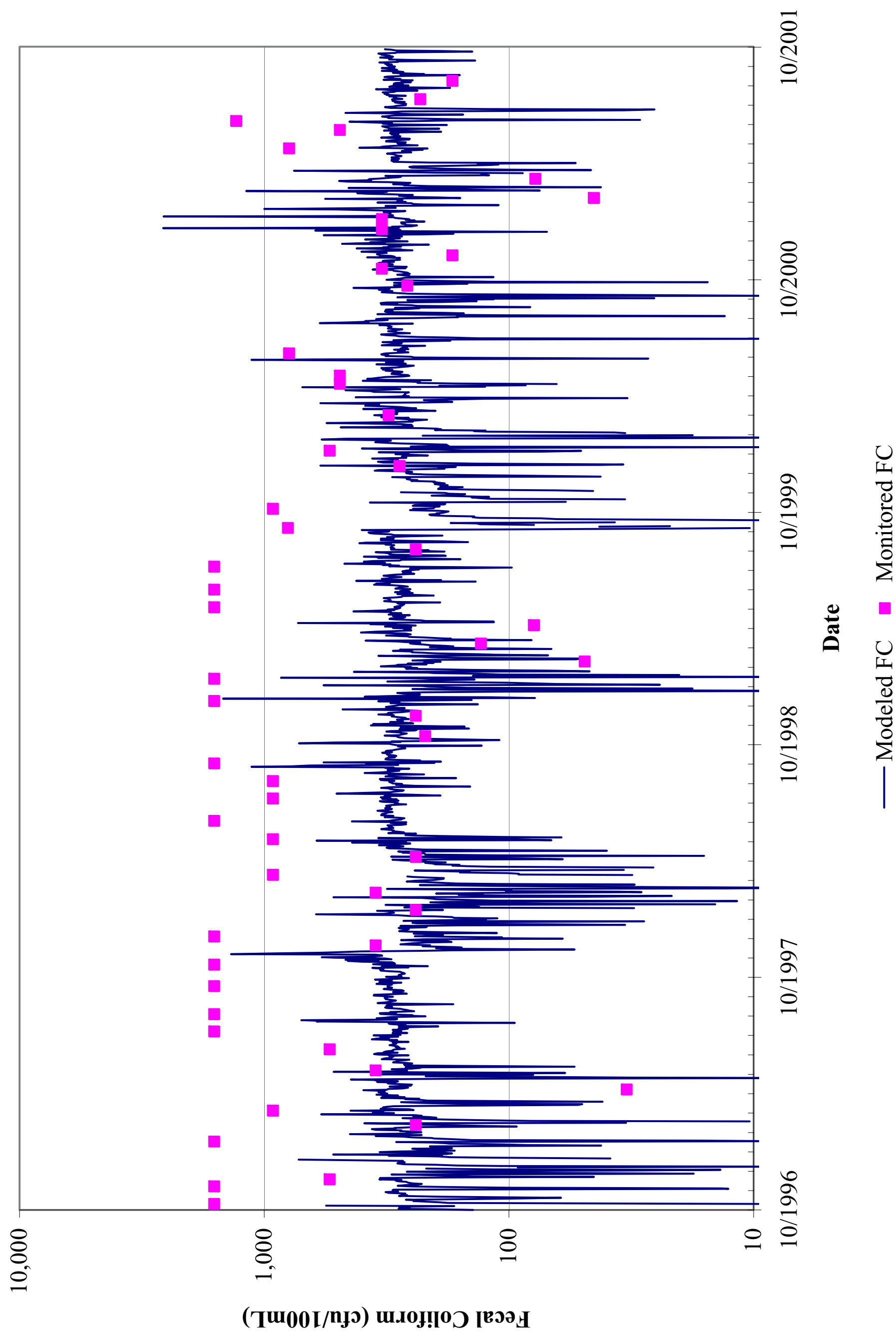

Figure 4.18 Fecal coliform quality calibration results for 10/1/1996 to 9/30/2001 for subwatershed 2, Nansemond River (Upper) impairment.

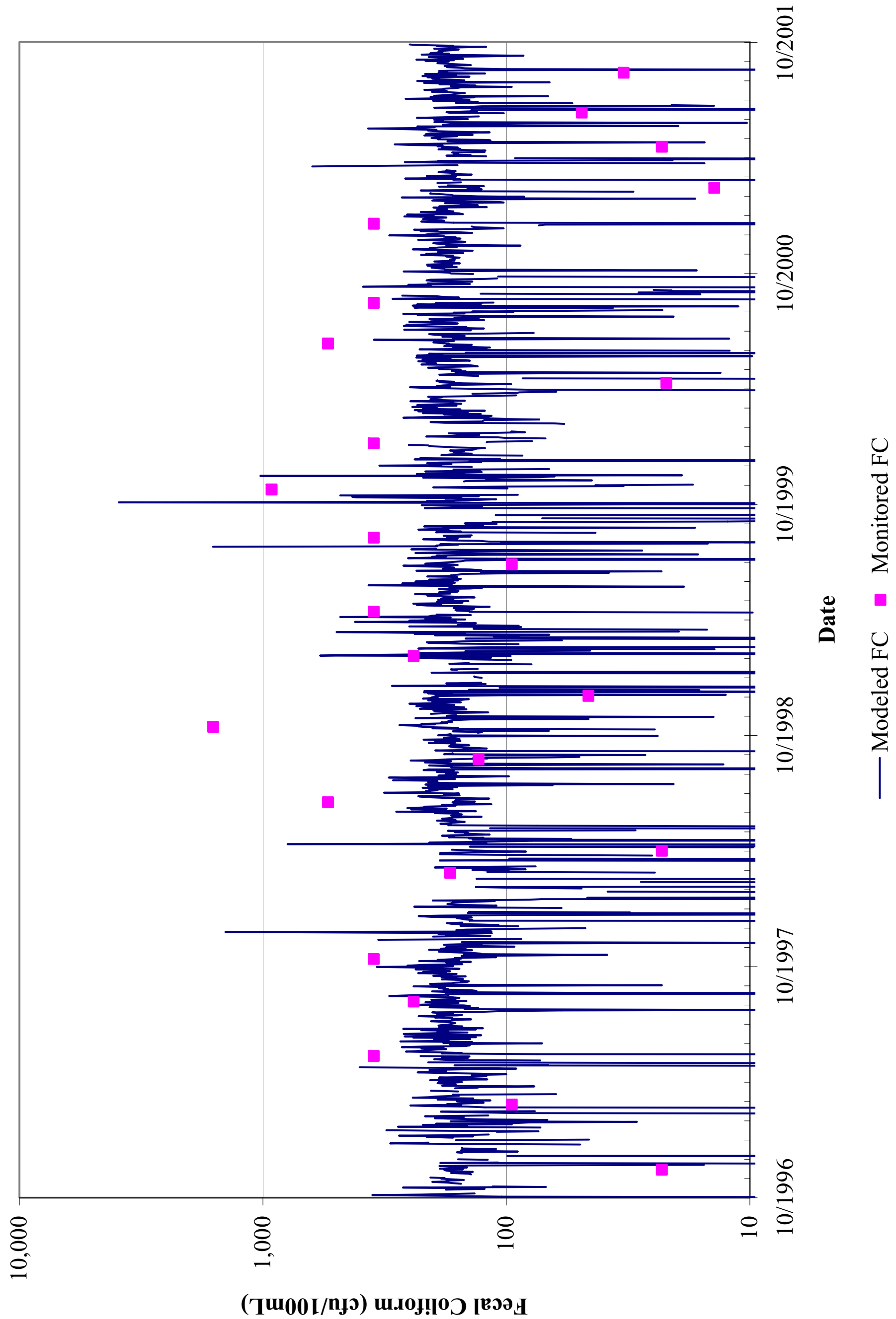

Figure 4.19 Fecal coliform quality calibration results for 10/1/1996 to 9/30/2001 for subwatershed 3, Nansemond River (Lake Meade Dam) impairment.

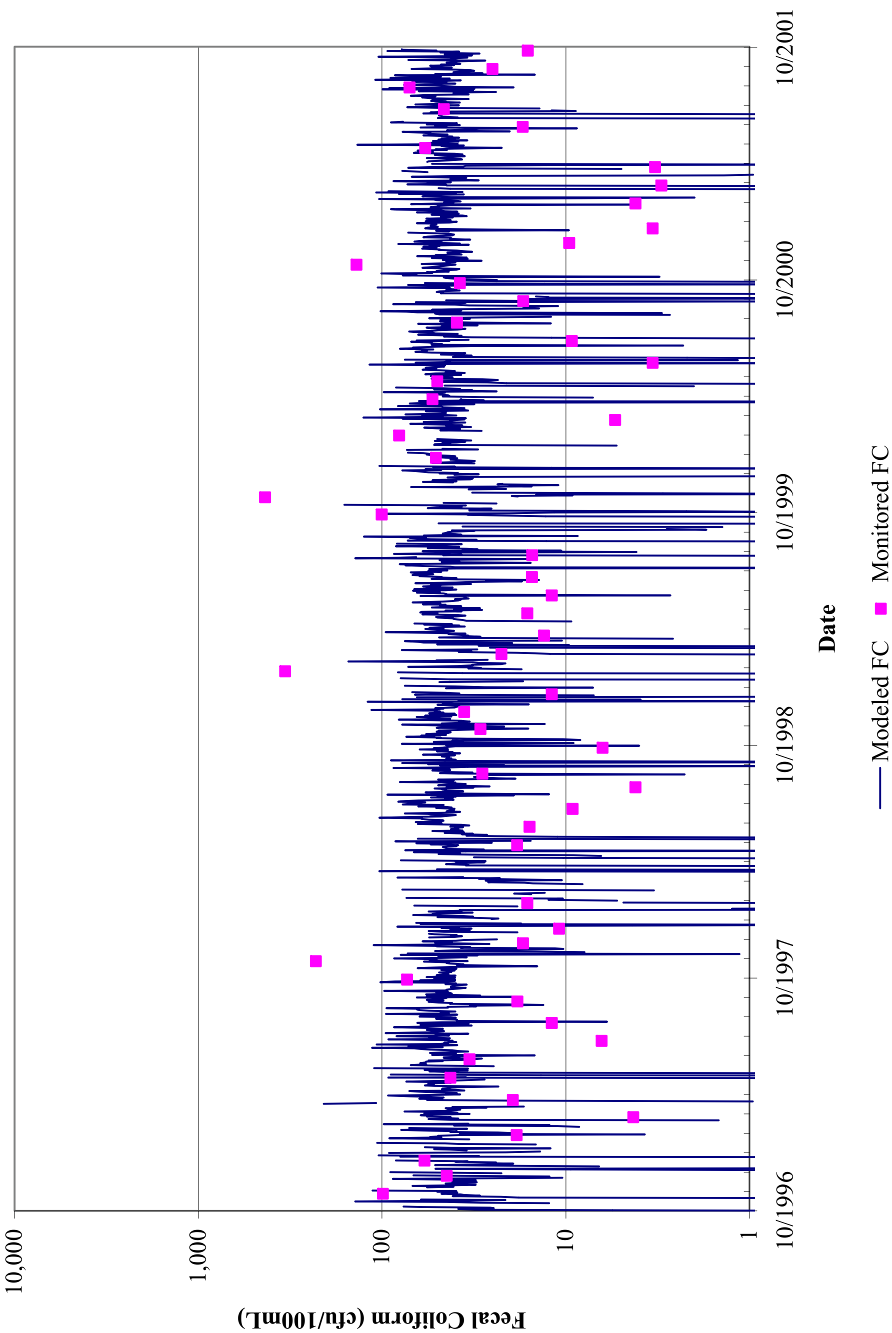

Figure 4.20 Fecal coliform quality calibration results for 10/1/1996 to 9/30/2001 for subwatershed 4, Nansemond River and Tributaries impairment.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$\textit{Standard Error} = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{(n-1)}}}{\sqrt{n}}$$

where

$$\begin{aligned} observed &= \text{an observed value of fecal coliform} \\ modeled_i &= \text{a modeled value in the 2-day window surrounding the observation} \\ n &= \text{the number of modeled observations in the 2-day window} \end{aligned}$$

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. Additionally, the maximum concentration values observed in the simulated data were compared with maximum values obtained from uncensored data (Chapter 2) and found to be at reasonable levels (Table 4.13). The standard errors in Table 4.13 range from a low of 3.28 to a high of 93.99. Even the highest value in this range can be considered quite reasonable when one takes into account the censoring of maximum values that is practiced in the collection of actual water quality samples. The standard error will be biased upwards when an observed high value censored at 8,000 cfu is compared to a simulated high value that may be an order of magnitude or more above the censor limit. Thus, the standard errors calculated for these impairments are considered an indicator of strong model performance.

Table 4.13 Mean standard error of the fecal coliform calibrated model for Nansemond River (10/1/1996 through 9/30/2001).

Impairment	Station	Mean Standard Error (cfu/100 mL)	Maximum Simulated Value (cfu/100 mL)	Maximum Monitored Value (cfu/100 mL)
Shingle Creek	2-SGL001.00 and 2-SGL001.50	40.72	20,711	1,600
Nansemond River (Upper)	2-NAN019.14	93.99	2,588	16,000
Nansemond River (Lake Meade Dam)	2-NAN013.50	67.57	3,913	1,600
Nansemond River and Tributaries	63-6 thru 63-11	3.28	208	432

Table 4.14 shows the predicted and observed values for the geometric mean and 90^{th} percentile (of all data within the time period) for all impaired stream segments. The maximum percent difference between modeled and monitored geometric means and the 90^{th} percentiles are within the standard deviation of the observed data at each station and, therefore, the fecal coliform calibration is acceptable.

Table 4.14 Comparison of modeled and observed geometric means.

Subwatershed	Station ID	Modeled Calibration Load Fecal Coliform 10/1/96 - 9/30/01			Monitored Fecal Coliform 10/1/96-9/30/01		
		n^1	Geometric Mean (cfu/100ml)	90th Percentile (cfu/100ml)	n^1	Geometric Mean (cfu/100ml)	90th Percentile (cfu/100ml)
5	2-SGL001.00 and 2-SGL001.50	1824	508	761	89	701	1,600
2	2-NAN019.14	1824	223	341	57	561	1,600
3	2-NAN013.50	1824	94	217	25	144	540
4	63-6 thru 63-11	1824	34	65	56	22	90

4.7.3 Fecal Coliform Water Quality Validation

Fecal coliform water quality model validation was performed on data from 1/1/1990 to 9/30/1995. The results are shown in Tables 4.15 and 4.16 and Figures 4.21 through 4.24. The standard errors in the Nansemond River model validation range from a low of 7.67 to a high of 119.76 (Table 4.15).

Table 4.15 Mean standard error of the fecal coliform calibrated model for Nansemond River (1/1/1990 through 9/30/1995).

Impairment	Station	Mean Standard Error (cfu/100 mL)	Maximum Simulated Value (cfu/100 mL)	Maximum Monitored Value (cfu/100 mL)
Shingle Creek	2-SGL001.00 and 2-SGL001.50	119.76	6,467	8,000
Nansemond River (Upper)	2-NAN019.14	108.68	1,101	8,000
Nansemond River (Lake Meade Dam)	2-NAN013.50	41.40	5,017	1,500
Nansemond River and Tributaries	63-6 thru 63-11	7.67	330	244

Table 4.16 shows the predicted and observed values for the geometric mean and 90th percentile (of all data within the time period) for all impaired stream segments. The maximum percent difference between modeled and monitored geometric means and the 90th percentiles are within the standard deviation of the observed data at each station and, therefore, the fecal coliform validation is acceptable.

Table 4.16 Comparison of modeled and observed geometric means.

Subwatershed	Station ID	Modeled Calibration Load Fecal Coliform 1/1/90 - 9/30/95			Monitored Fecal Coliform 1/1/90 - 9/30/95		
		n^1	Geometric Mean (cfu/100ml)	90^{th} Percentile (cfu/100ml)	n^1	Geometric Mean (cfu/100ml)	90^{th} Percentile (cfu/100ml)
5	2-SGL001.00 and 2-SGL001.50	1824	559	784	67	659	2,420
2	2-NAN019.14	1824	248	343	72	744	3,050
3	2-NAN013.50	1824	118	223	13	141	1,036
4	63-6 thru 63-11	1824	39	66	68	17	65

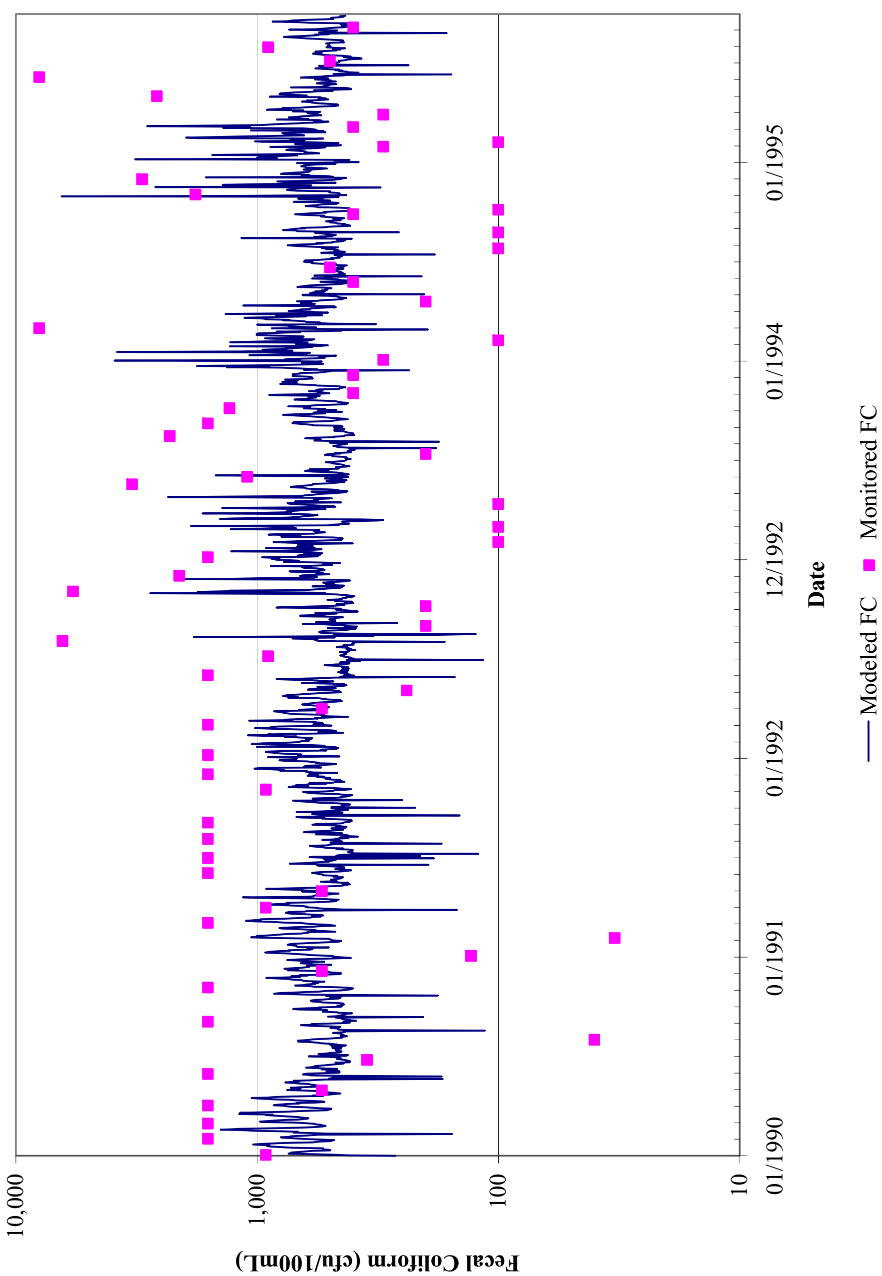

Figure 4.21 Fecal coliform quality validation results for 1/1/1990 to 9/30/1995 for subwatershed 5, Shingle Creek impairment.

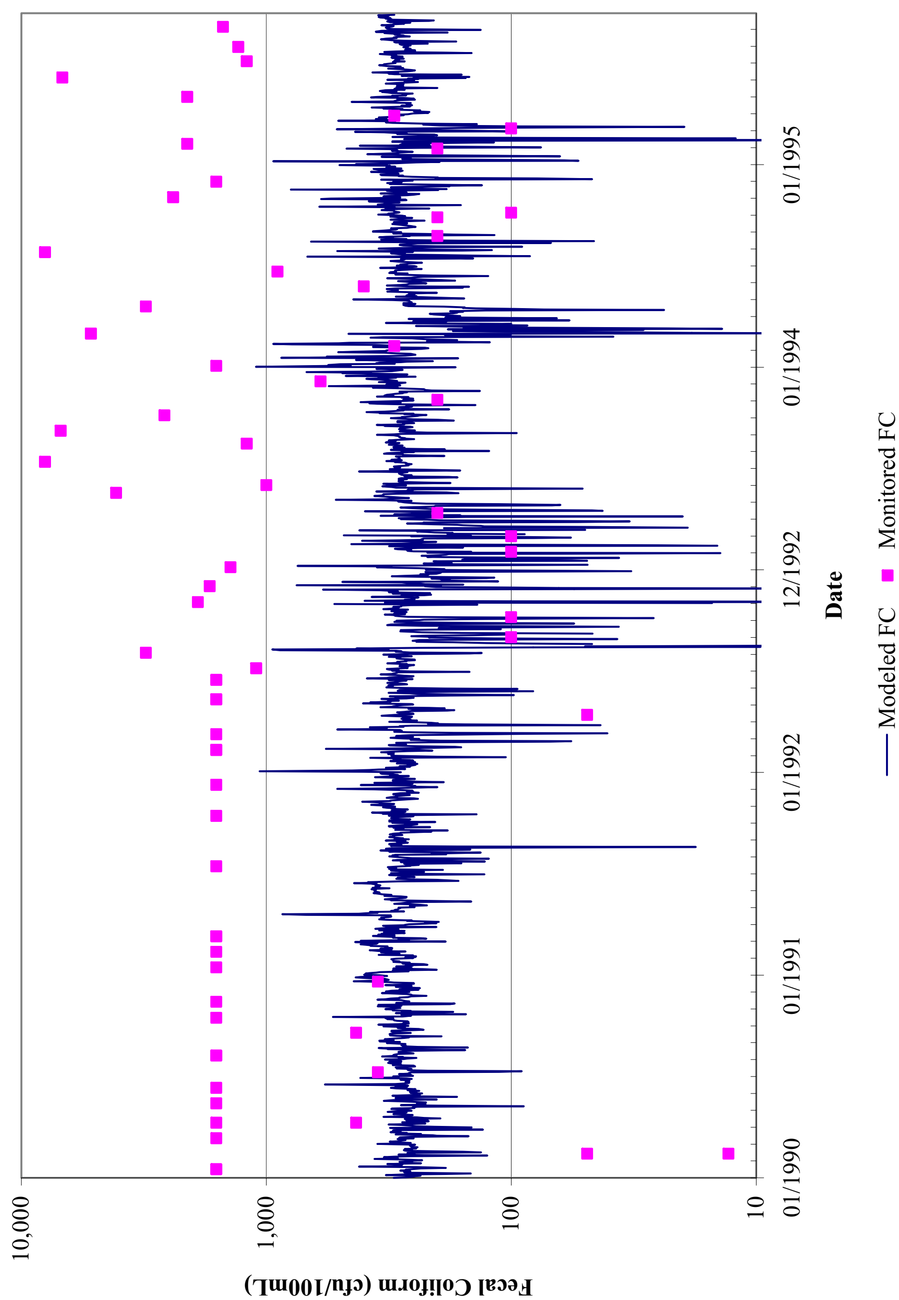

Figure 4.22 Fecal coliform quality validation results for 1/1/1990 to 9/30/1995 for subwatershed 2, Nansemond River (Upper) impairment.

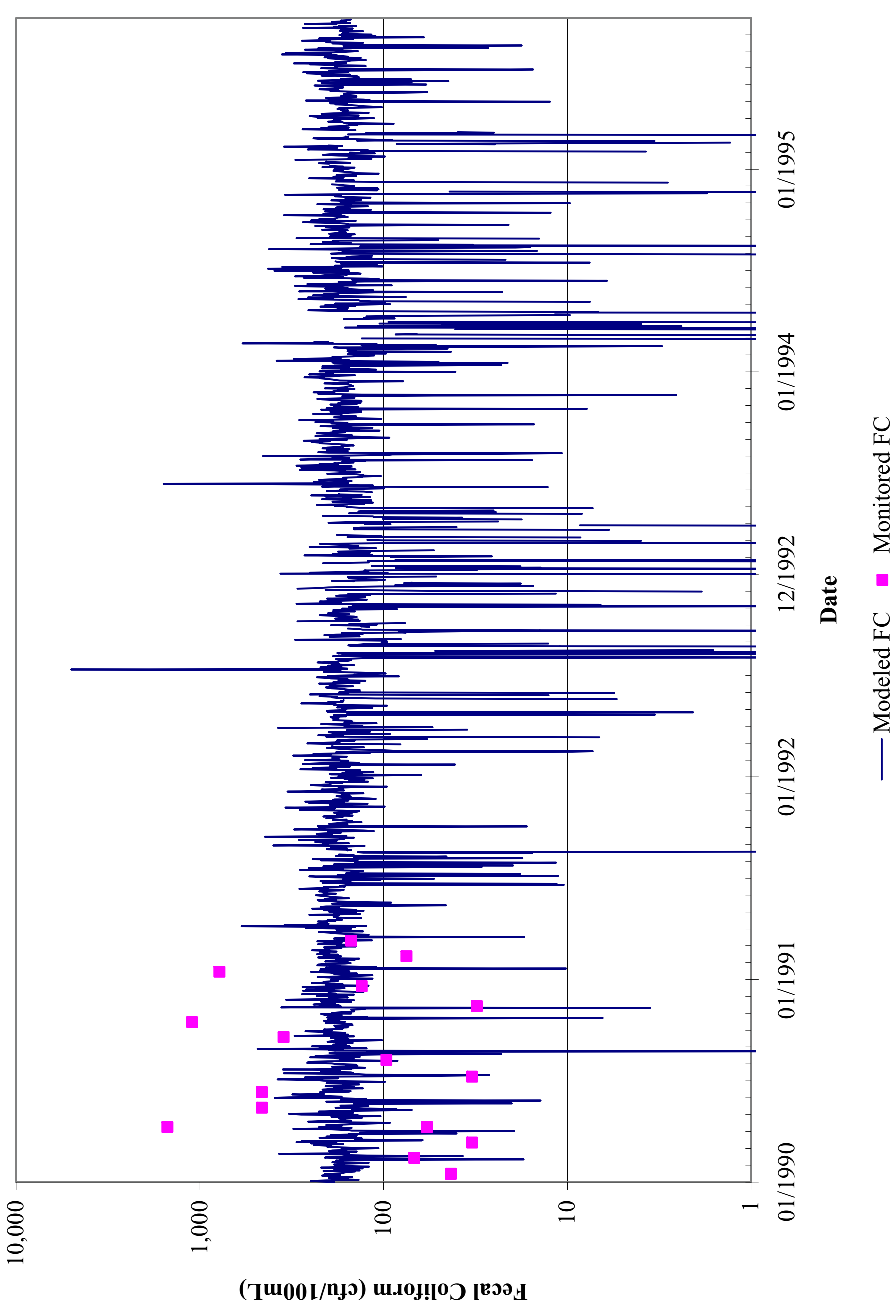

Figure 4.23 Fecal coliform quality validation results for 1/1/1990 to 9/30/1995 for subwatershed 3, Nansemond River (Lake Meade Dam) impairment.

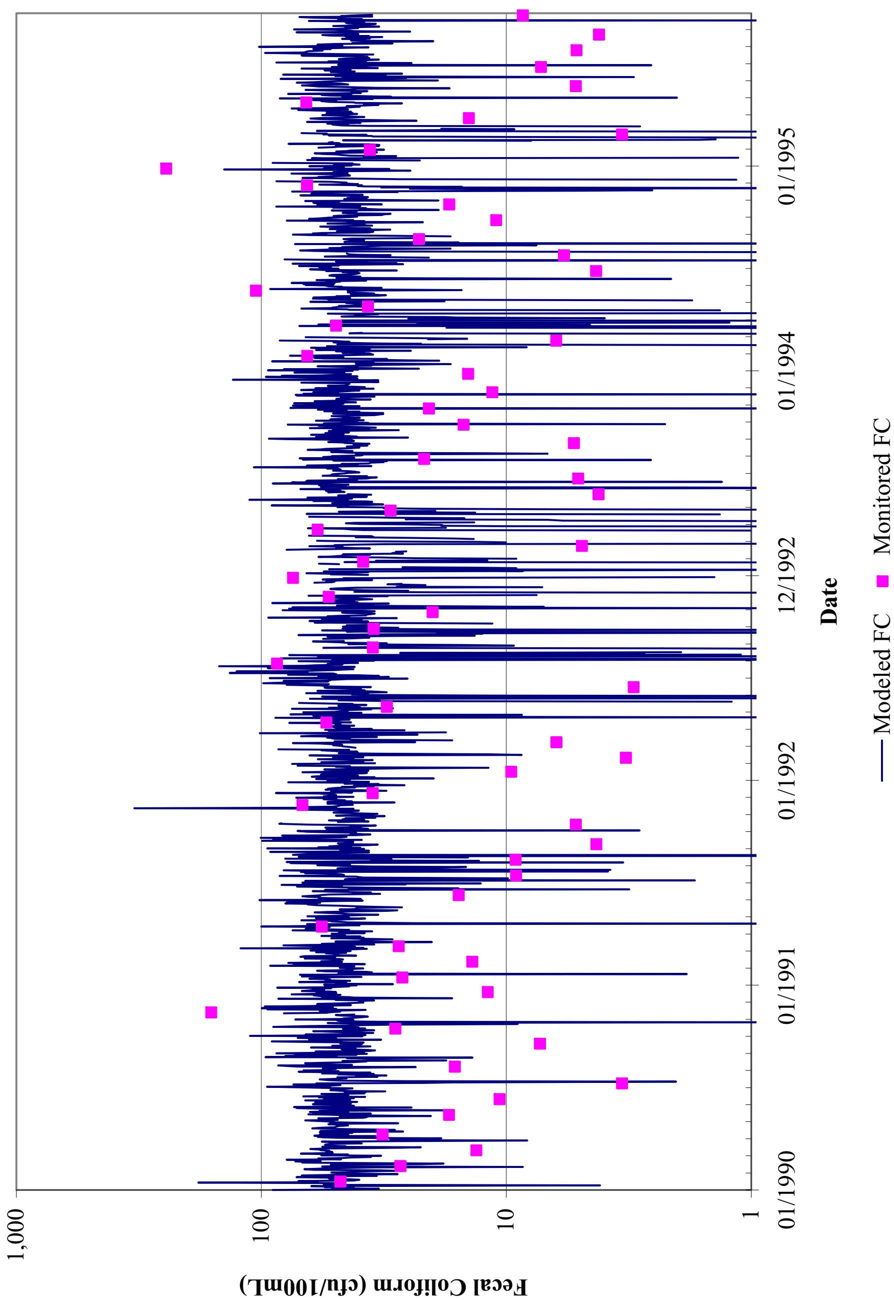

Figure 4.24 Fecal coliform quality validation results for 1/1/1990 to 9/30/1995 for subwatershed 4, Nansemond River and Tributaries impairment.

4.8 Existing Loadings

All appropriate inputs were updated to 2006 conditions. All model runs were conducted using precipitation data during hydrologic calibration. Figures 4.25, 4.27 and 4.29 show the monthly geometric mean of *enterococci* concentrations in relation to the 35-cfu/100mL standard for Shingle Creek, Nansemond (Upper) and Nansemond (Lake Meade Dam) impairments, respectively. Figures 4.26, 4.28 and 4.30 show the instantaneous values of *enterococci* concentrations in relation to the 104-cfu/100mL standard for Shingle Creek, Nansemond (Upper) and Nansemond (Lake Meade Dam) impairments, respectively. Gaps shown in the instantaneous graphs represent *enterococci* values of zero due to zero stream flow out of the reach.

Shingle Creek and the Nansemond River are also impaired for the shellfish harvesting use, which uses fecal coliform standards. Figures 4.31 and 4.32 show the existing modeled fecal coliform values for Shingle Creek regarding the geometric mean and 90th percentile standards, 14 cfu/100mL and 49 cfu/100mL, respectively. Figures 4.32 and 4.33 show the existing modeled fecal coliform values at the Nansemond River and Tributaries impairment outlet regarding the geometric mean and 90th percentile standards. Appendix B contains tables with monthly loadings to the different land use areas in each subwatershed.

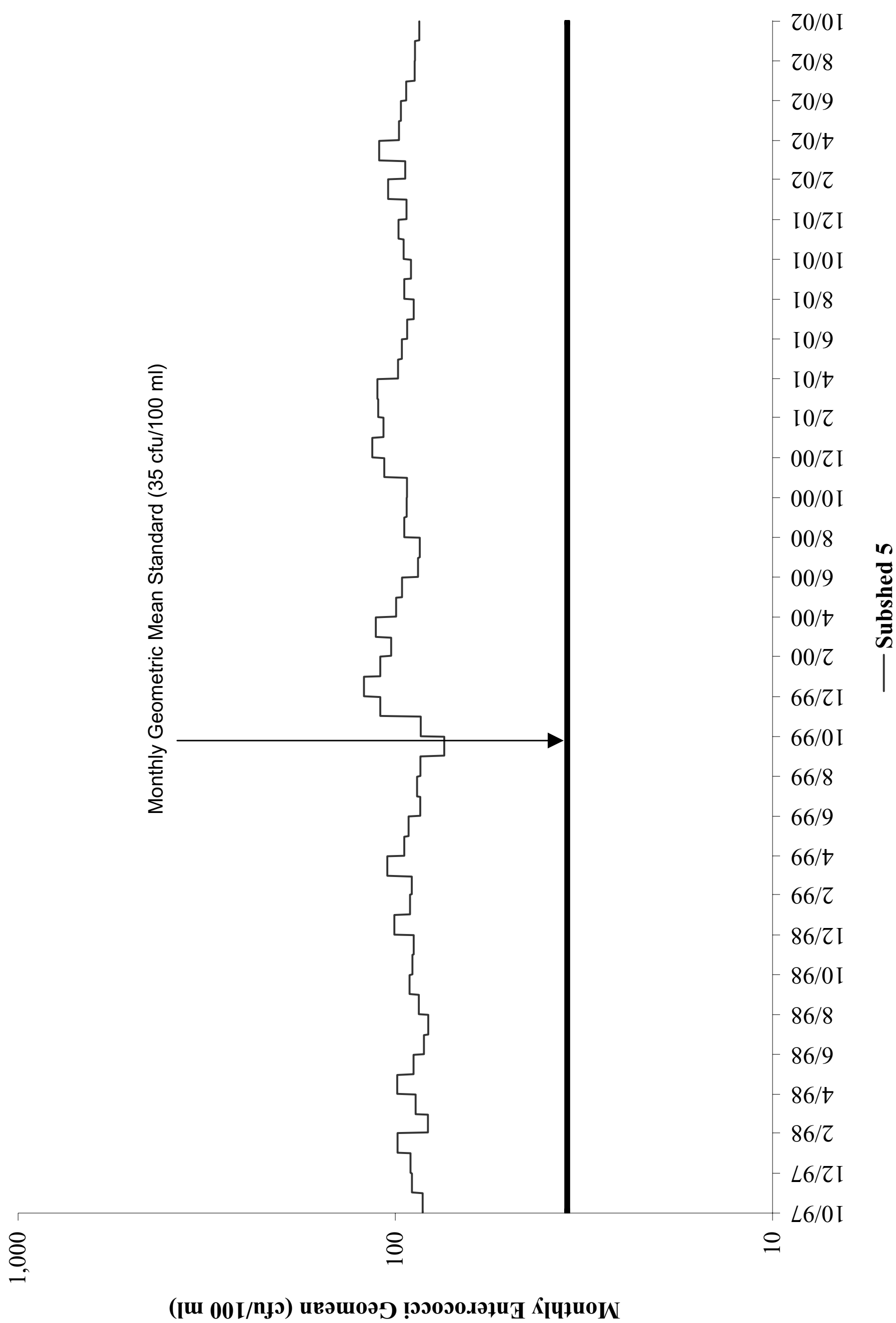

Figure 4.25 Existing conditions (*i.e.*, monthly geometric mean) of *enterococci* concentrations Shingle Creek impairment outlet (subwatershed 5).

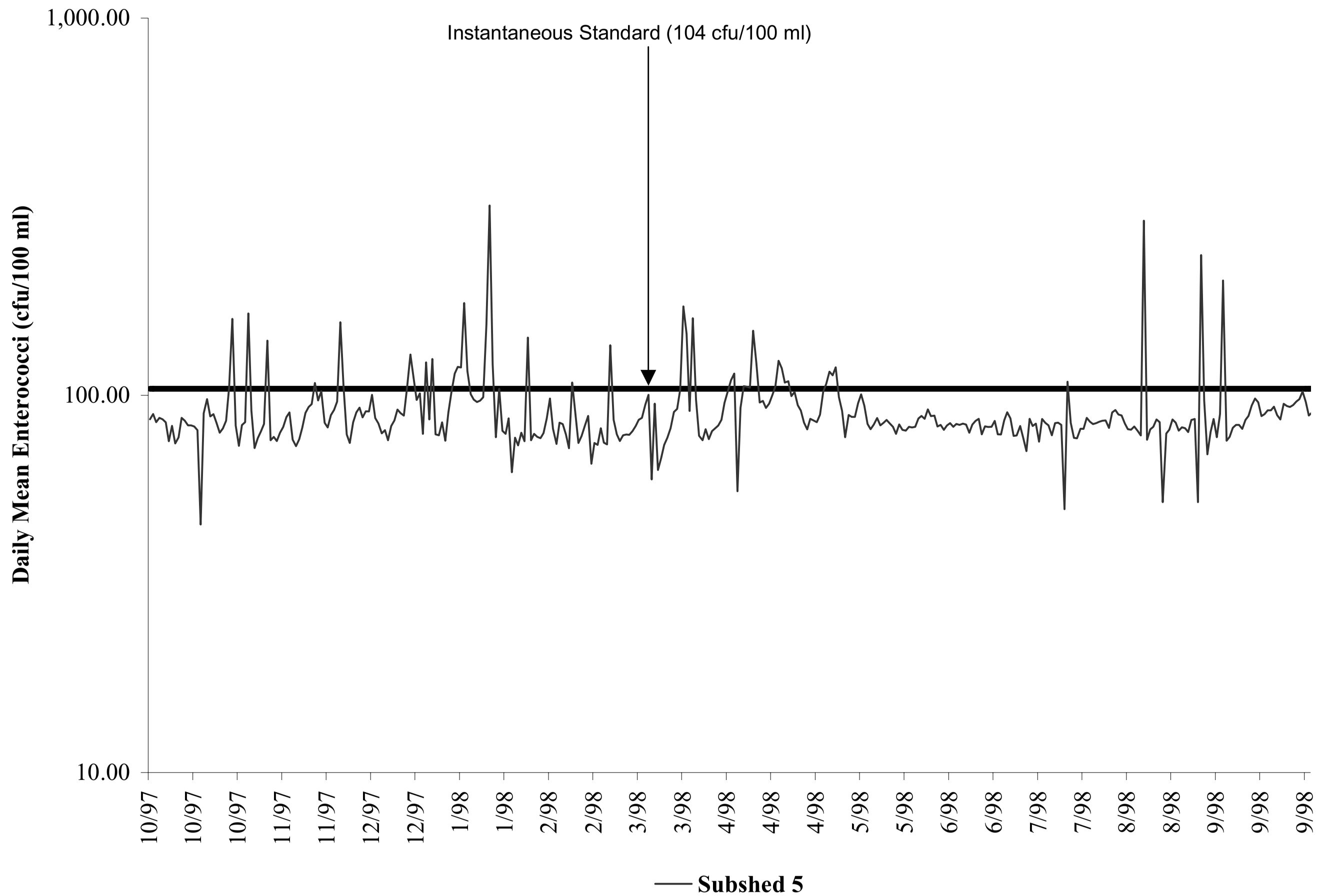

Figure 4.26 Existing conditions (*i.e.*, mean daily) of *enterococci* concentrations, Shingle Creek impairment outlet (subwatershed 5).

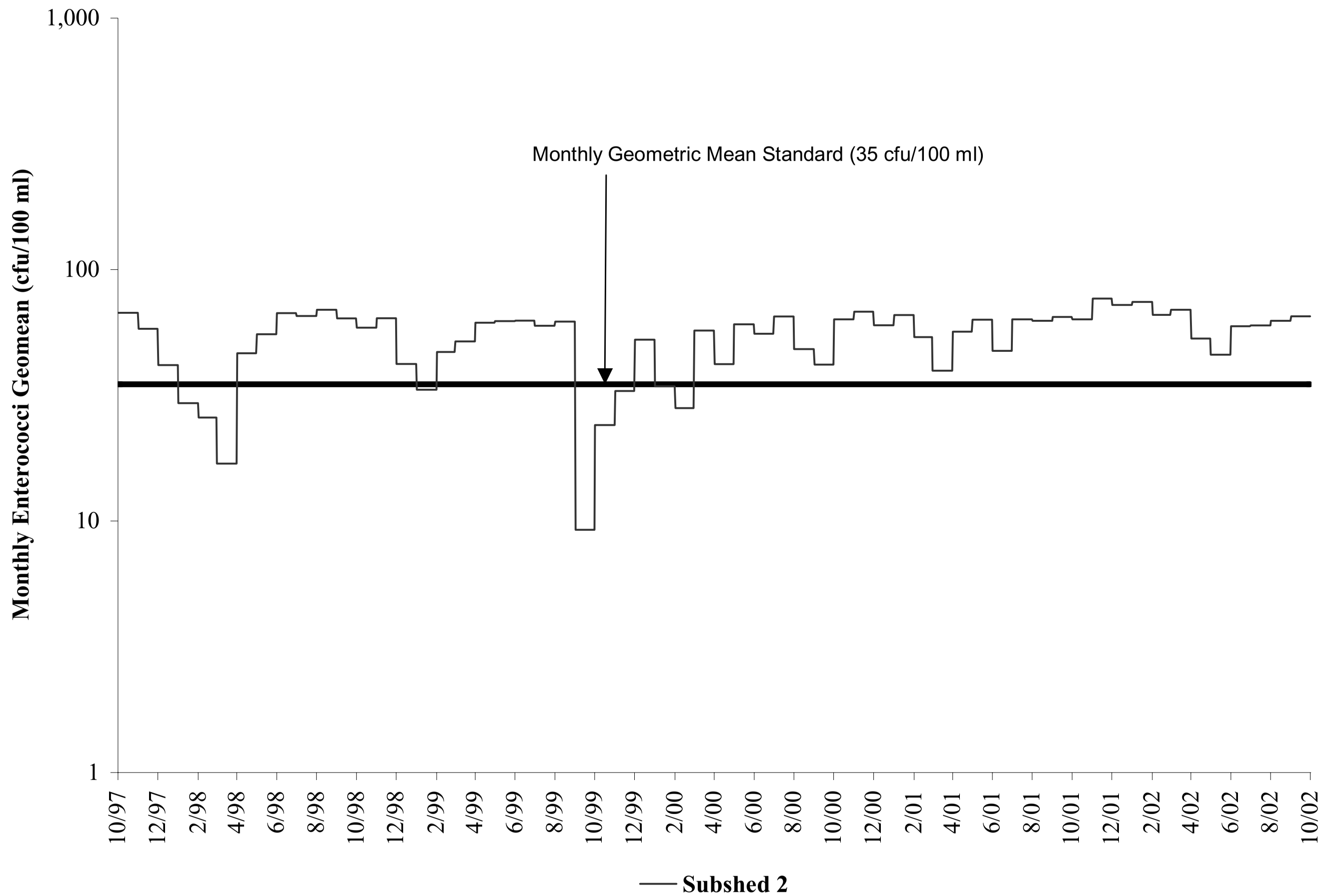

Figure 4.27 Existing conditions (*i.e.*, monthly geometric mean) of *enterococci* concentrations Nansemond (Upper) impairment outlet (subwatershed 2).

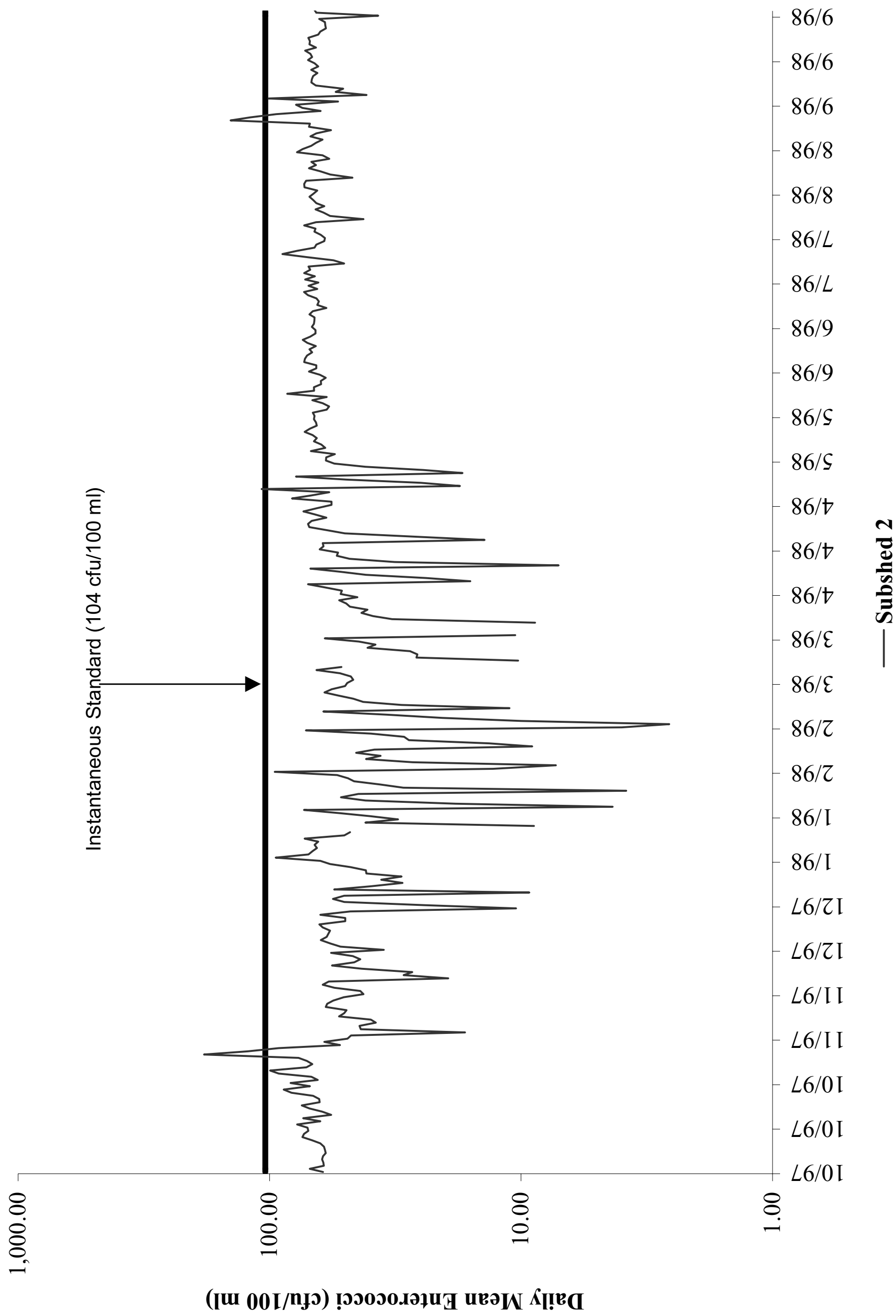

Figure 4.28 Existing conditions (*i.e.*, mean daily) of *enterococci* concentrations, Nansemond (Upper) impairment outlet (subwatershed 2).

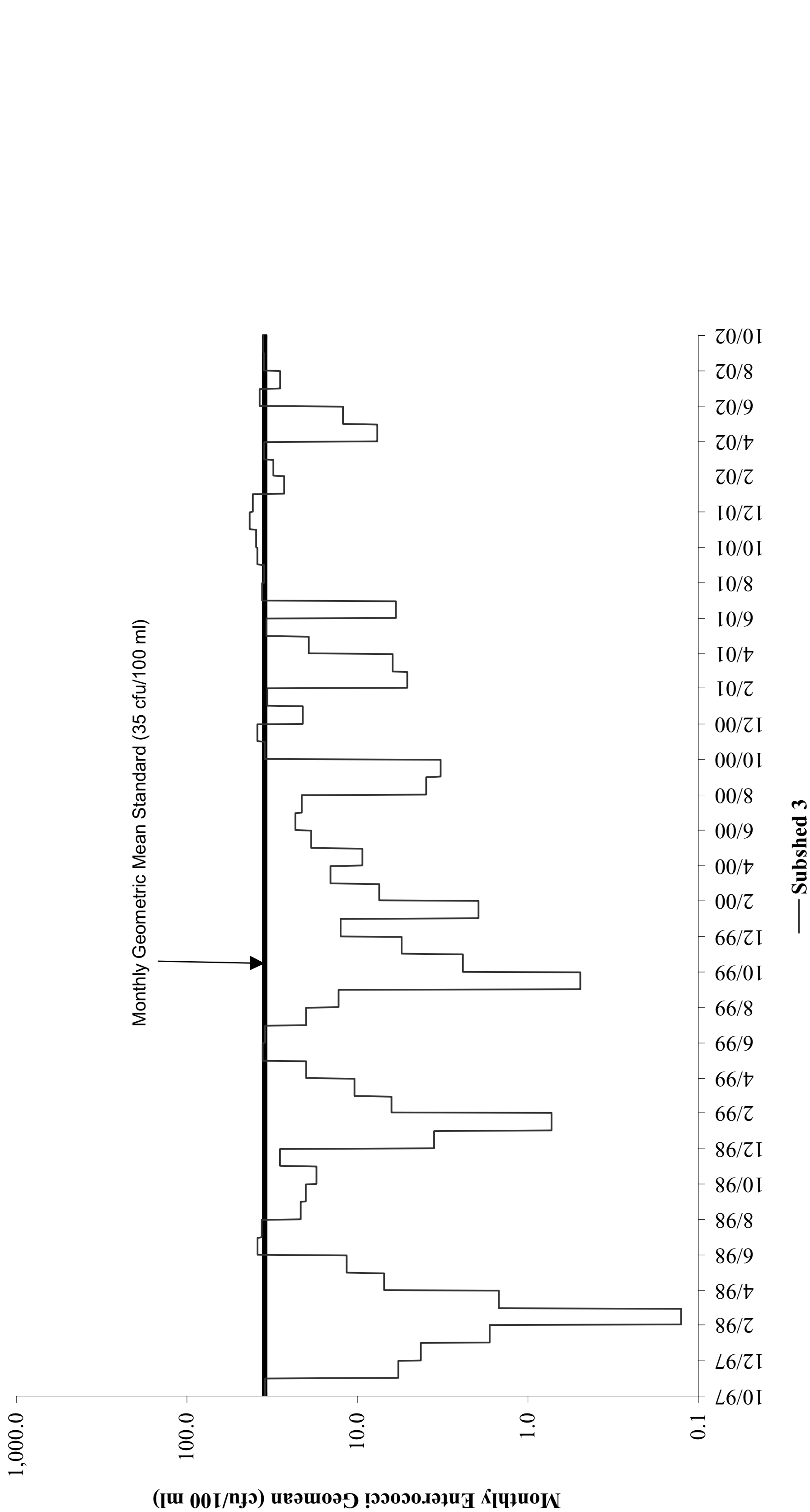

Figure 4.29 Existing conditions (*i.e.*, monthly geometric mean) of *enterococci* concentrations Nansemond (Lake Meade Dam) impairment outlet (subwatershed 3).

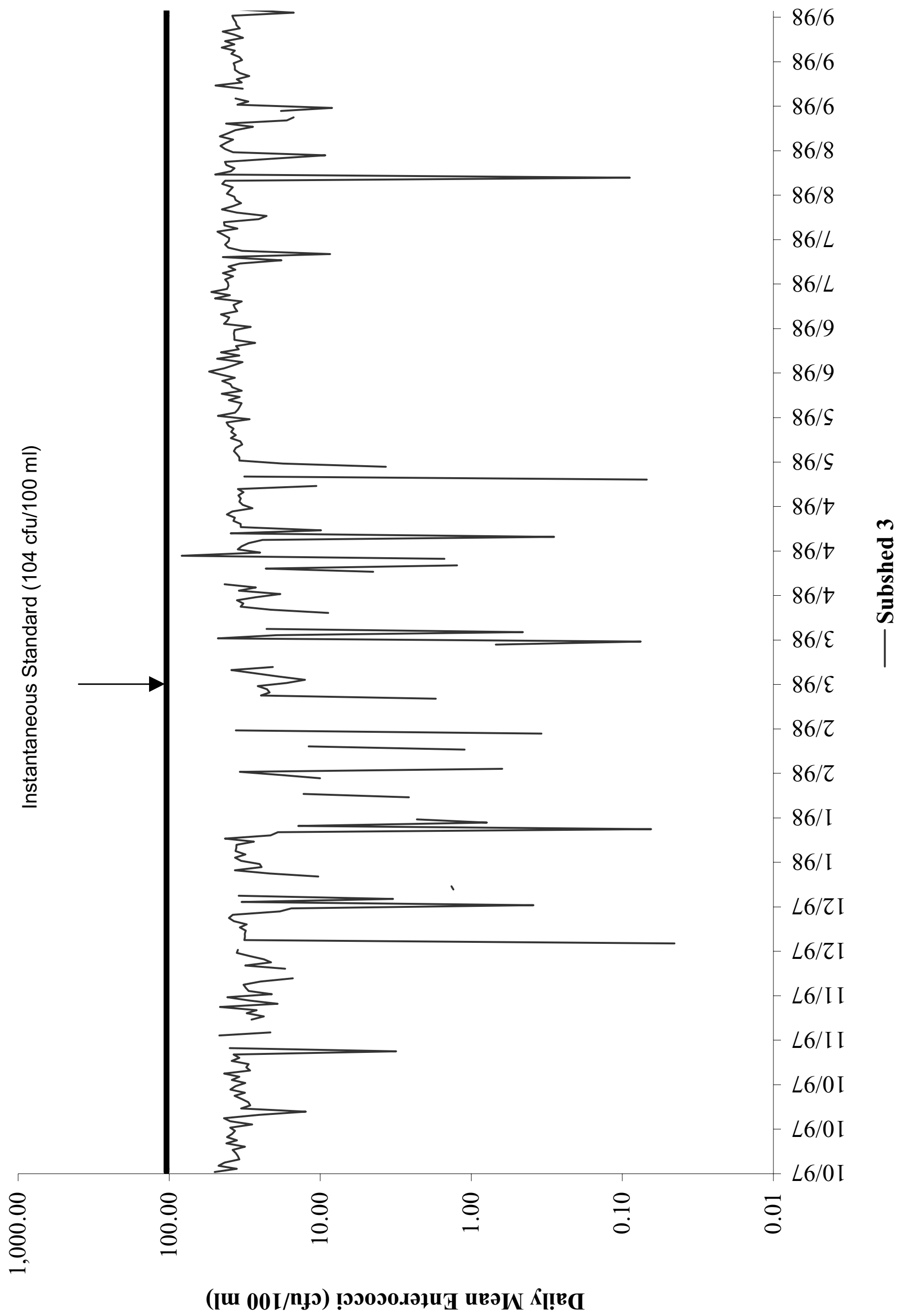

Figure 4.30 Existing conditions (*i.e.*, mean daily) of *enterococci* concentrations, Nansemond (Lake Meade Dam) impairment outlet (subwatershed 3).

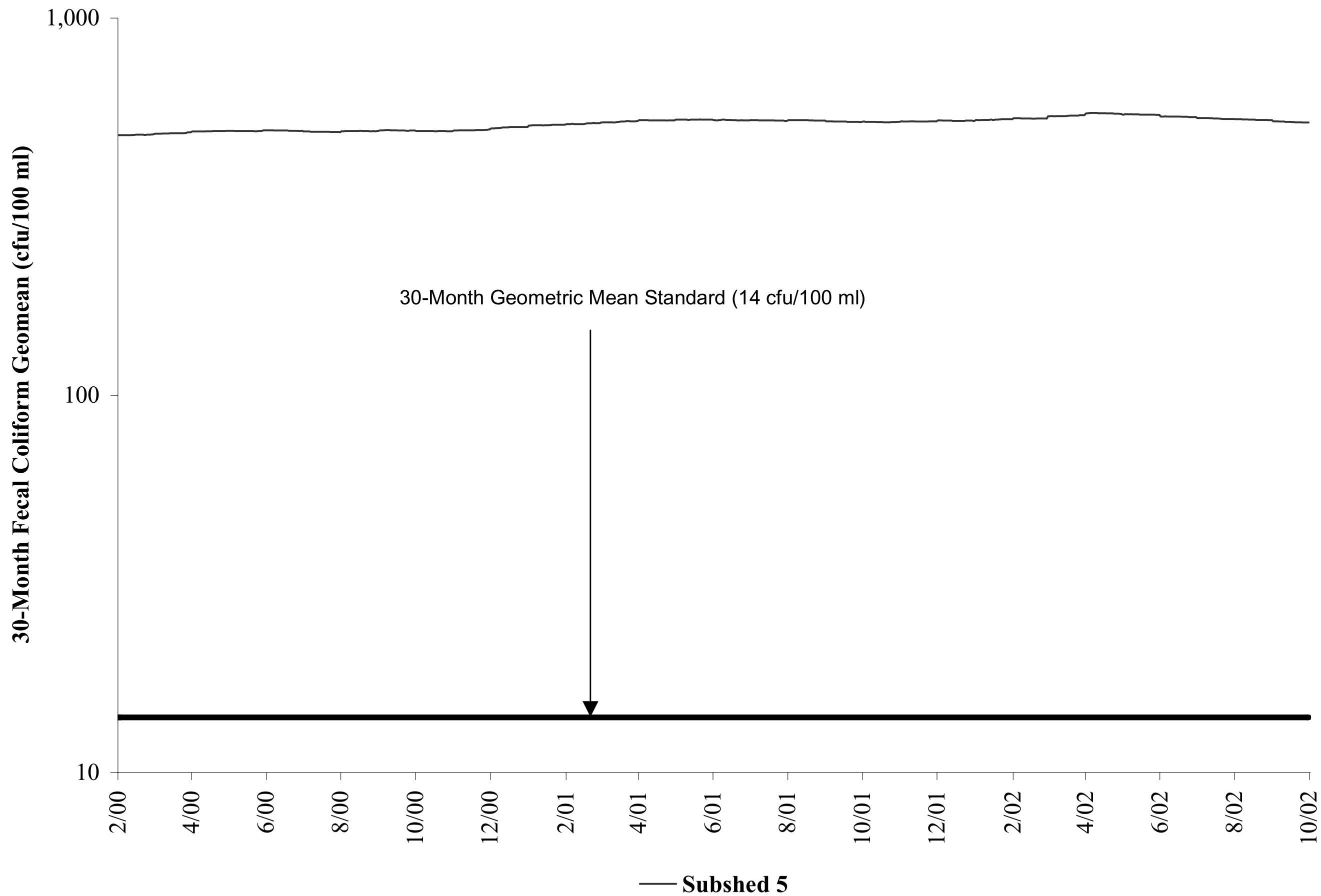

Figure 4.31 Existing conditions (*i.e.*, 30-month geometric-mean) of fecal coliform concentrations Shingle Creek impairment outlet (subwatershed 5).

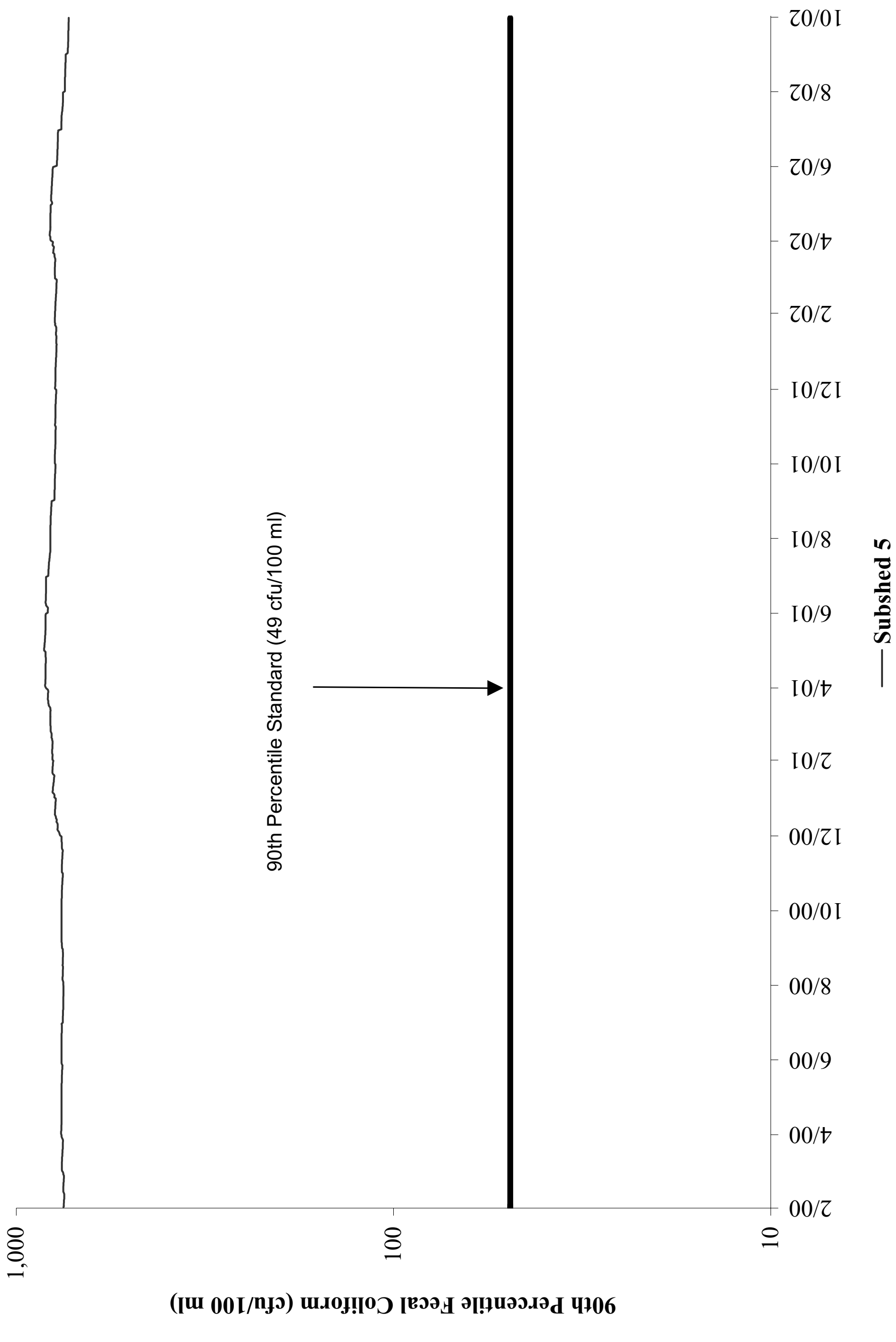

Figure 4.32 Existing conditions (*i.e.*, 30-month 90th percentile) of fecal coliform concentrations, Nansemond (Lake Meade Dam) impairment outlet (subwatershed 3).

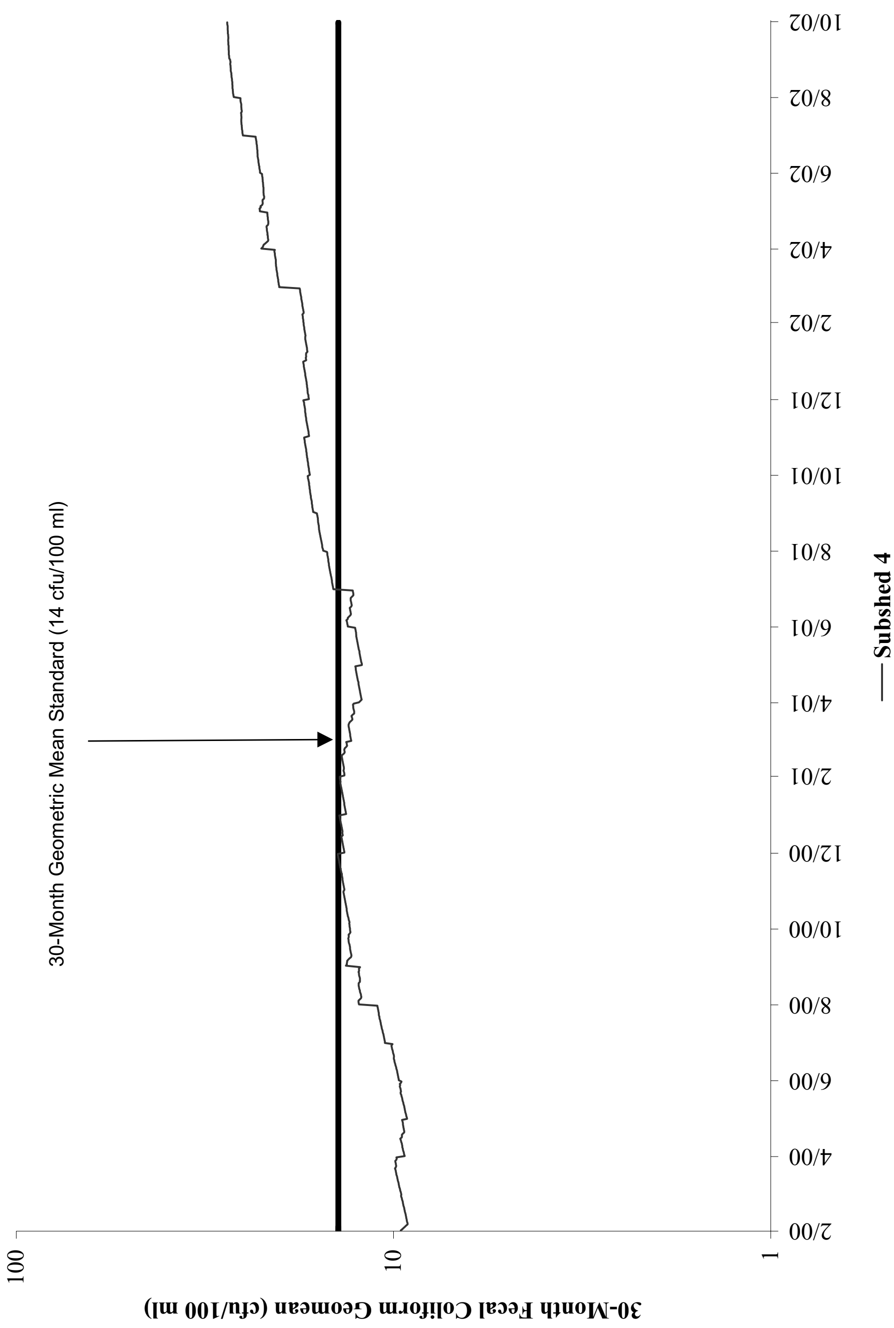

Figure 4.33 Existing conditions (*i.e.*, 30-month geometric-mean) of fecal coliform concentrations Nansemond River and tributaries impairment outlet (subwatershed 4).

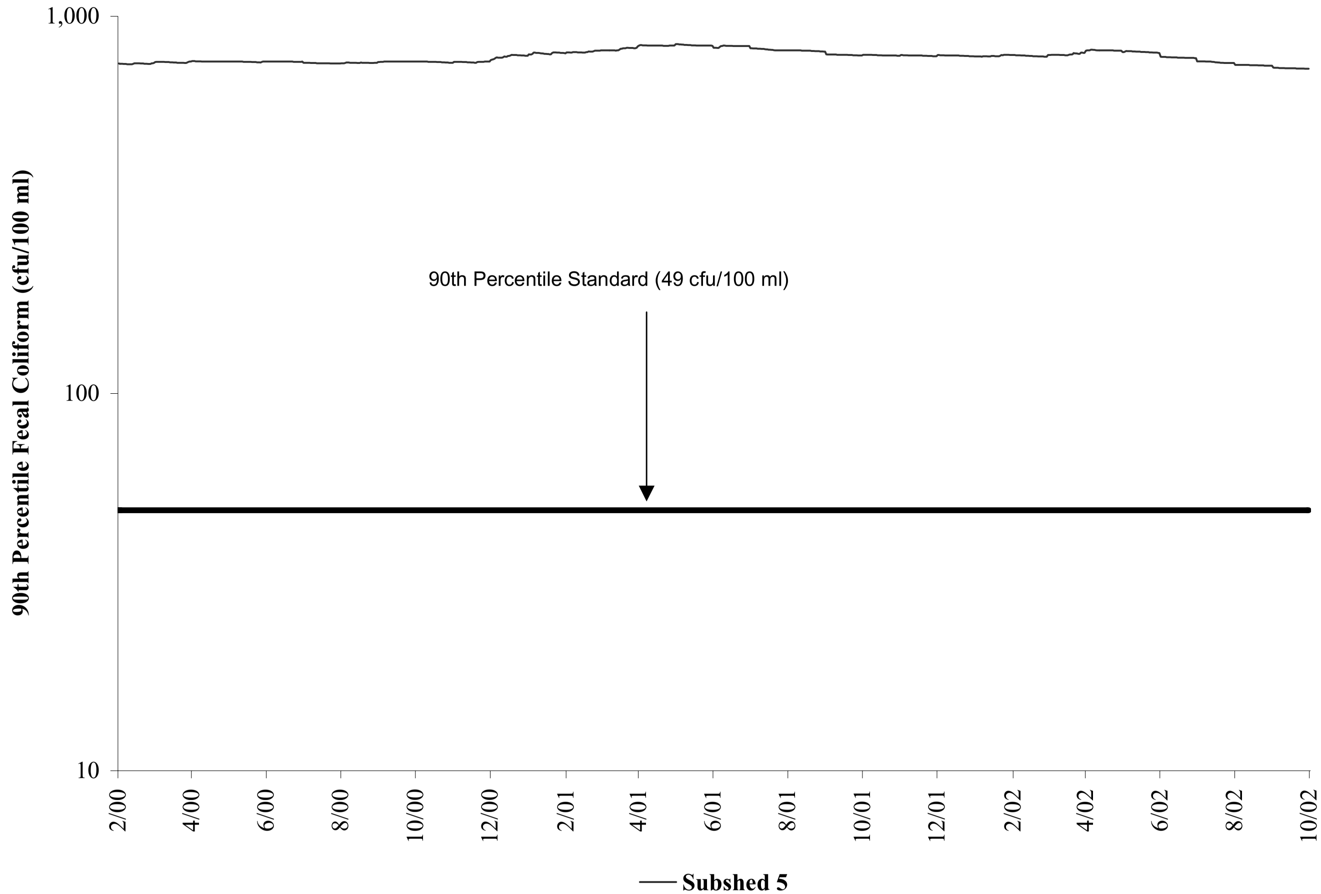

Figure 4.34 Existing conditions (*i.e.*, 30-month 90th percentile) of fecal coliform concentrations Nansemond River and tributaries impairment outlet (subwatershed 4).

5. ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, nonpoint sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.*, accuracy of wildlife populations). The definition is typically denoted by the expression:

TMDL = WLAs + LAs + MOS

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For fecal coliform bacteria, the TMDL is expressed in terms of colony forming units (or resulting concentration). A sensitivity analysis was performed to determine the impact of uncertainties in input parameters.

5.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, a MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. A margin of safety can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of an MOS in the development of a fecal coliform TMDL is to ensure that the modeled loads do not underestimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of this TMDL. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will in fact succeed in meeting the water quality standard. Examples of the implicit MOS used in the development of this TMDL are:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration, and

- Selecting a modeling period that represented the critical hydrologic conditions in the watershed.

5.2 Scenario Development

Allocation scenarios were modeled using HSPF. Existing conditions were adjusted until the water quality standard was attained. The TMDL developed for the Nansemond River watershed was based on the Virginia State Standard for *E. coli* and *enterococci*. As detailed in section 2.1, the *E. coli* standard states that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 ml, and that a maximum single sample concentration of *E. coli* shall not exceed 235 cfu/100 ml. The *enterococci* standard states that the calendar month geometric-mean concentration shall not exceed 35 cfu/100 ml, and that a maximum single sample concentration of *enterococci* shall not exceed 104 cfu/100 ml. According to the guidelines put forth by the VADEQ (VADEQ, 2003) for modeling *E. coli* with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* and *enterococci* through the use of the following equation (developed from a data set containing n-493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc}) \qquad \textit{E. coli}$$

$$\log_2(C_{ent}) = 1.2375 + 0.59984 \cdot \log_2(C_{fc}) \qquad \textit{Enterococci}$$

where C_{ec} is the concentration of *E. coli* in cfu/100 mL, C_{ent} is the concentration of *enterococci* in cfu/100 mL and C_{fc} is the concentration of fecal coliform in cfu/100 mL.

Pollutant concentrations were modeled over the entire duration of a representative modeling period and pollutant loads were adjusted until the standard was met. The development of the allocation scenario was an iterative process that required numerous runs with each followed by an assessment of source reduction against the water quality target.

5.2.1 Waste Load Allocations

There are seven point sources that currently discharge fecal bacteria into the Nansemond River watershed section 3.2. The allocation for the sources permitted for fecal control is equivalent to their current permit levels (design discharge and 14 fecal coliform cfu/100 ml or 35 cfu/100 *enterococci*).

5.2.2 Load Allocations

Load allocations to nonpoint sources are divided into land-based loadings from land uses and directly applied loads in the stream (*e.g.,* livestock, sewer overflows, and wildlife). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads had their most significant impact during high-flow conditions, while direct deposition NPS had their most significant impact on low flow concentrations. The BST results confirmed the presence of human, livestock, pet, and wildlife contamination. Load reductions were performed by land use, as opposed to reducing sources, as it is considered that the majority of BMPs will be implemented by land use. Reductions on agricultural land uses (pasture and cropland) include reductions required for land applied livestock wastes.

Allocation scenarios were run sequentially, beginning with headwater impairments, and then continuing with downstream impairments until all impairments were allocated to 0% exceedances of the all applicable standards. Tables 5.1 through 5.4 represent a small portion of the scenarios developed to determine the TMDL for each impairment. The first four scenarios were run for all impairments simultaneously; subsequent runs were made after upstream impairments were allocated. Scenario 1 in each table describes a baseline scenario that corresponds to the existing conditions in the watershed.

Reduction scenarios exploring the role of anthropogenic sources in standards violations were explored first to determine the feasibility of meeting standards without wildlife reductions. In each table, Scenario 2 eliminated direct human sources (straight pipes and sewer overflows). Since part of the TMDL development is the identification of phased implementation strategies, typical management scenarios were explored as well. Scenario 3 in each contains reductions of 50% in all anthropogenic land-based loads, 100% reduction in sewer overflows and uncontrolled residential discharges, a 90% or 100% reduction in direct livestock deposition, and a 0% reduction in wildlife direct and land-based loading to the stream. Scenario 4 attempts to determine the impact of nonanthropogenic sources (*i.e.,* wildlife), by exploring 100% reductions in all anthropogenic land-based and direct loads. In most cases, the model predicts that water quality standards will not be met without reductions in wildlife loads. Further scenarios in each table explore a range of management scenarios, leading to the final allocation scenario that contains the predicted reductions needed to meet 0% exceedance of all applicable water quality standards.

5.2.2.1 Shingle Creek – VADEQ Primary Contact Recreational Use and Shellfish Harvesting Use

Table 5.1 shows allocation scenarios used to determine the final TMDL for Shingle Creek. Because Virginia's standards do not permit any exceedances, modeling was conducted for a target value of 0% exceedance of both VADEQ and VDH standards for Shingle Creek. The existing condition, Scenario 1, shows that VADEQ primary contact recreational geometric mean standard and both VDH shellfish standards are exceeded 100% of the time. Although the existing conditions had high percent violations for all standards, Scenario 2 (eliminating direct human inputs) showed dramatic improvement in meeting the VADEQ standards. The typical management scenario, Scenario 3, slightly improved the violations of the VADEQ standards. This scenario showed improvement, but the standards were still not met. Scenario 4 shows 100% reductions to all anthropogenic sources; however, exceedances persisted. This scenario shows that reductions to wildlife loads must be made. Scenario 5 had fewer reductions to agricultural and urban nonpoint source loads to provide more obtainable scenarios (99%).

Scenario 6 meets all standards with 98% reductions to both direct and land-based wildlife loads. The direct wildlife reduction at 97% still allows Shingle Creek to meet all standards. The subsequent scenarios show that fewer reductions to direct livestock, land-based agricultural loads, and land-based residential loads will not meet the VADEQ geometric mean standard. Therefore, Scenario 7 is the final TMDL scenario.

Table 5.1 Allocation scenarios for bacterial concentration with current loading estimates in subwatershed 5, Shingle Creek.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations of VADEQ standards		Percent Violations of VDH standards	
	Direct Wildlife Loads	NPS Forest/ Wetlands	Direct Livestock Loads	NPS Agricultural Land	Direct Human Loads	NPS Residential Land	Geometric Mean > 35 cfu/100ml	Single Sample > 104 cfu/100ml	Geometric Mean > 14 cfu/100ml	90th Percentile > 49 cfu/100ml
1	0	0	0	0	0	0	100%	23%	100%	100%
2[2]	0	0	0	0	100	0	2%	3%	100%	100%
3	0	0	90	50	100	50	0%	3%	100%	100%
4	0	0	100	100	100	100	0%	2%	100%	100%
5	0	0	100	99	100	99	0%	2%	100%	100%
6	98	98	100	99	100	99	0%	0%	0%	0%
7[1]	97	98	100	99	100	99	0%	0%	0%	0%
8	97	98	100	99	100	98	1%	0%	0%	0%
9	97	98	100	98	100	99	2%	0%	0%	0%
10	97	98	99	99	100	99	2%	0%	0%	0%

[1]Final TMDL Scenario
[2]Stage 1 Implementation Scenario

5.2.2.2 Nansemond River (Upper) – VADEQ Primary Contact Recreational Use and Shellfish Harvesting Use (part of condemnation zone #8)

Table 5.2 shows allocation scenarios used to determine the final TMDL for Nansemond River (Upper). This impairment is located in subwatershed 2 which includes most of downtown Suffolk, VA. Because Virginia's standards do not permit any exceedances, modeling was conducted for a target value of 0% exceedance of both VADEQ and VDH standards for the Nansemond River. The existing condition, Scenario 1, shows that both VDH shellfish standards are exceeded 100% of the time and there is an 85% violations of the VADEQ geometric mean. Scenario 2 (eliminating direct human inputs) showed dramatic improvement in meeting the standards. The typical management scenario, Scenario 3, did not show improvement in the conditions in the river. Scenario 4 shows 100% reductions to all anthropogenic sources; however, exceedances still persisted. This scenario shows that reductions to wildlife loads must be made. Scenario 5 had fewer reductions to agricultural and urban nonpoint source loads to provide more obtainable scenarios (99%).

With Shingle Creek allocated (Shingle Creek flows into Nansemond (Upper)) and 96% reductions to both direct and land-based wildlife loads, Scenario 7 meets all standards except the VDH geometric mean. With land-based loadings on forest and wetlands at a 97% reduction, all standards are met. Fewer reductions to land-based agriculture and residential loads (96%) still met the standards (Scenario 9). Scenario 10 shows that 0% of direct livestock reduction are required. This subwatershed represents the urban area of downtown Suffolk, VA, so this final TMDL scenario is reasonable. Therefore, Scenario 10 is the final TMDL scenario.

Table 5.2 Allocation scenarios for bacterial concentration with current loading estimates in subwatershed 2, Upper Nansemond River.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations of VADEQ standards		Percent Violations of VDH standards	
	Direct Wildlife Loads	NPS Forest/ Wetlands	Direct Livestock Loads	NPS Agricultural Land	Direct Human Loads	NPS Residential Land	Geometric Mean > 35 cfu/100ml	Single Sample > 104 cfu/100ml	Geometric Mean > 14 cfu/100ml	90th Percentile > 49 cfu/100ml
1	0	0	0	0	0	0	85%	1%	100%	100%
2[2]	0	0	0	100	0	0	2%	1%	100%	100%
3	0	0	90	100	50	50	2%	1%	100%	100%
4	0	0	100	100	100	100	0%	0%	100%	100%
5	0	0	100	99	100	100	0%	1%	100%	100%
6	Scenario 5 with Shingle Creek allocated (subwatershed 5)						0%	0%	100%	100%
7	96	96	100	99	100	99	0%	0%	1%	0%
8	96	97	100	99	100	99	0%	0%	0%	0%
9	96	97	100	96	100	96	0%	0%	0%	0%
10[1]	96	97	0	96	100	96	0%	0%	0%	0%

[1]Final TMDL Scenario
[2]Stage 1 Implementation Scenario

5.2.2.3 Nansemond River (Lake Meade Dam) – VADEQ Primary Contact Recreational Use and Shellfish Harvesting Use (part of condemnation zone #8)

Table 5.3 shows allocation scenarios used to determine the final TMDL for Nansemond River (Lake Meade Dam). Because Virginia's standards do not permit any exceedances, modeling was conducted for a target value of 0% exceedance of both VADEQ and VDH standards for the Nansemond River. The existing condition, Scenario 1, shows that both VDH shellfish standards are exceeded 100% of the time and there is an 85% violations of the VADEQ geometric mean. Scenario 2 (eliminating direct human inputs) showed dramatic improvement in meeting the standards. These runs as well as Scenarios 3, 4 and 5 were made before the allocation of Shingle Creek and Nansemond River (Upper). Once these impairments were allocated, the violations in Nansemond River (Lake Meade Dam) improved dramatically. The only reduction required to meet all standards is 100% elimination of direct human sources (straight pipes and sewer overflows). Scenario 7 is the final TMDL scenario.

Table 5.3 Allocation scenarios for bacterial concentration with current loading estimates in subwatersheds 2 and 3, Nansemond River (Lake Meade).

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations of VADEQ standards		Percent Violations of VDH standards	
	Direct Wildlife Loads	NPS Forest/ Wetlands	Direct Livestock Loads	NPS Agricultural Land	Direct Human Loads	NPS Residential Land	Geometric Mean > 35 cfu/100ml	Single Sample > 104 cfu/100ml	Geometric Mean > 14 cfu/100ml	90th Percentile > 49 cfu/100ml
1	0	0	0	0	0	0	85%	1%	100%	100%
2	0	0	0	0	100	0	2%	1%	100%	100%
3	0	0	90	50	100	50	2%	1%	100%	100%
4	0	0	100	100	100	100	0%	0%	100%	100%
5	0	0	100	99	99	100	0%	1%	100%	100%
6	Scenario 5 with Shingle Creek and Nansemond (Upper) allocated (subwatersheds 5 and 2)						0%	0%	0%	0%
7[1, 2]	0	0	0	0	100	0	0%	0%	0%	0%

[1]Final TMDL Scenario
[2]Stage 1 Implementation Scenario

5.2.2.4 Nansemond River and Tributaries –Shellfish Harvesting Use (condemnation zone #8)

Table 5.4 shows allocation scenarios used to determine the final TMDL for Nansemond River and Tributaries. Scenarios made before upstream impairments were allocated show violations of all standards; however Scenario 6 shows that once all upstream allocations are made this impairment will come into compliance with the VDH standards. However, 100% reduction to straight pipes and sewer overflows is included in Scenario 7 to recognize that direct sewage discharge to the state's waters is illegal and should be corrected. Scenario 7 is the final TMDL scenario with 100% reduction of direct human sources (straight pipes and sewer overflows).

Table 5.4 Allocation scenarios for bacterial concentration with current loading estimates in subwatersheds 1-7, Nansemond River and tribs.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations of VDH standards	
	Direct Wildlife Loads	NPS Forest/ Wetlands	Direct Livestock Loads	NPS Agricultural Land	Direct Human Loads	NPS Residential Land	Geometric Mean > 14 cfu/100ml	90th Percentile > 49 cfu/100ml
1	0	0	0	0	0	0	47%	100%
2	0	0	0	0	100	0	0%	0%
3	0	0	90	50	100	50	0%	0%
4	0	0	100	100	100	100	0%	0%
5	0	0	100	99	99	100	0%	0%
6	Scenario 5 with upstream impairments allocated (subwatersheds 5, 2, and 3)						0%	0%
7[1, 2]	0	0	0	0	100	0	0%	0%

[1]Final TMDL Scenario
[2]Stage 1 Implementation Scenario

5.2.2.5 TMDL allocation results

Figures 5.1 through 5.3 show the daily average *enterococci* concentrations for existing and allocated conditions for the impairment in Shingle Creek, Nansemond River (Upper), and Nansemond River (Lake Meade Dam), respectively. Figures 5.4 through 5.6 show the corresponding results for the geometric means for existing and allocated conditions for the impairment in Shingle Creek, Nansemond River (Upper), and Nansemond (Lake Meade Dam), respectively. These graphs show existing conditions in gray, with allocated conditions overlaid in black.

Figures 5.7 and 5.9 show similar results for the VDH shellfish impairment in Shingle Creek. The 90th percentile of existing and allocated conditions is shown in Figure 5.7. The geometric mean results for existing and allocated conditions are shown in Figure 5.9. Figures 5.8 and 5.10 show the results for the VDH shellfish impairment Nansemond River and Tributaries. The 90th percentile of existing and allocated conditions is shown in Figure 5.8. The geometric mean results for existing and allocated conditions are shown in Figure 5.10.

Any breaks in the data shown in these graphs are due to the bacteria concentrations going to zero. This happened on days when there was zero discharge out of the reach (*i.e.,* when tide in was greater then runoff and tide out).

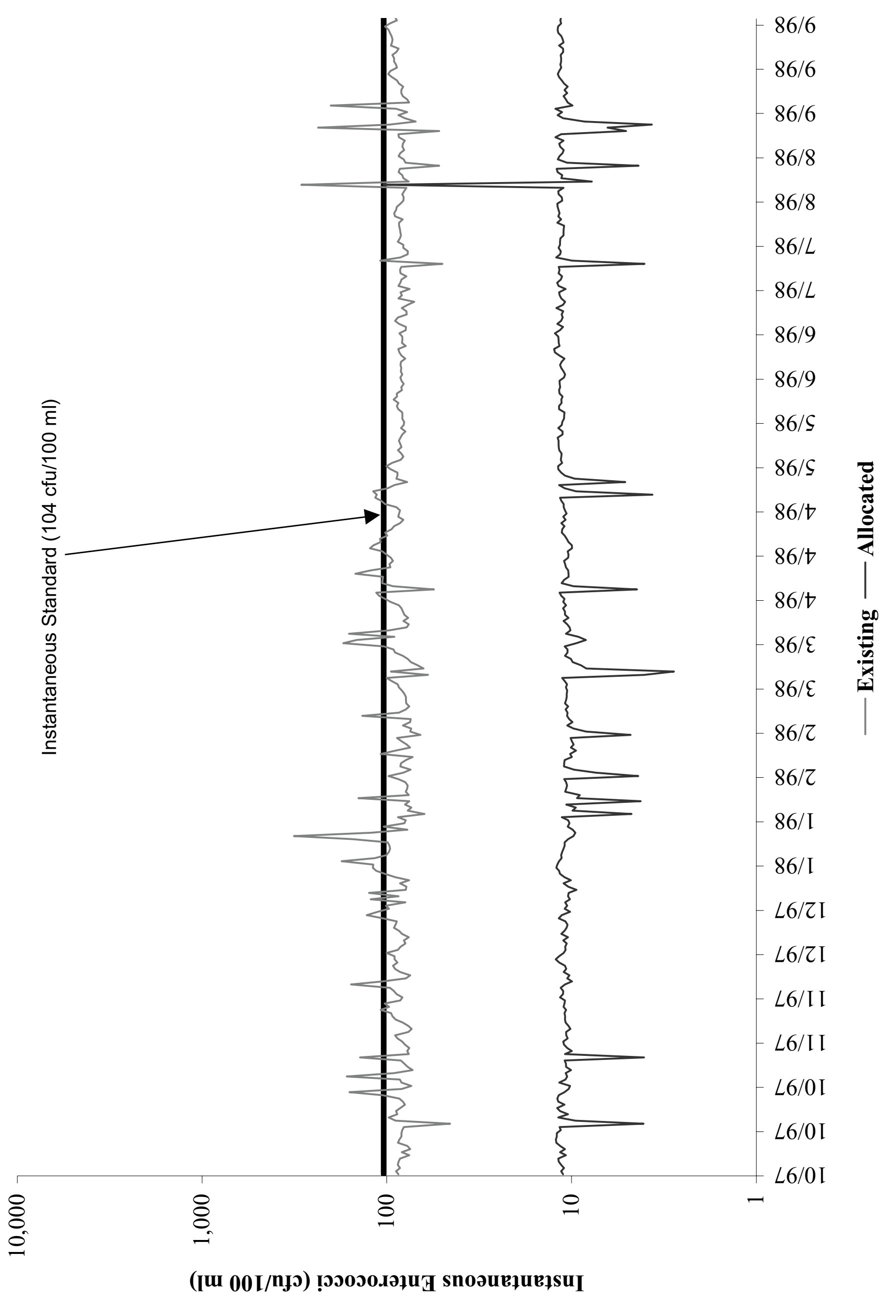

Figure 5.1 Existing and allocation scenarios of daily average *enterococci* concentrations in subwatershed 5, Shingle Creek impairment outlet.

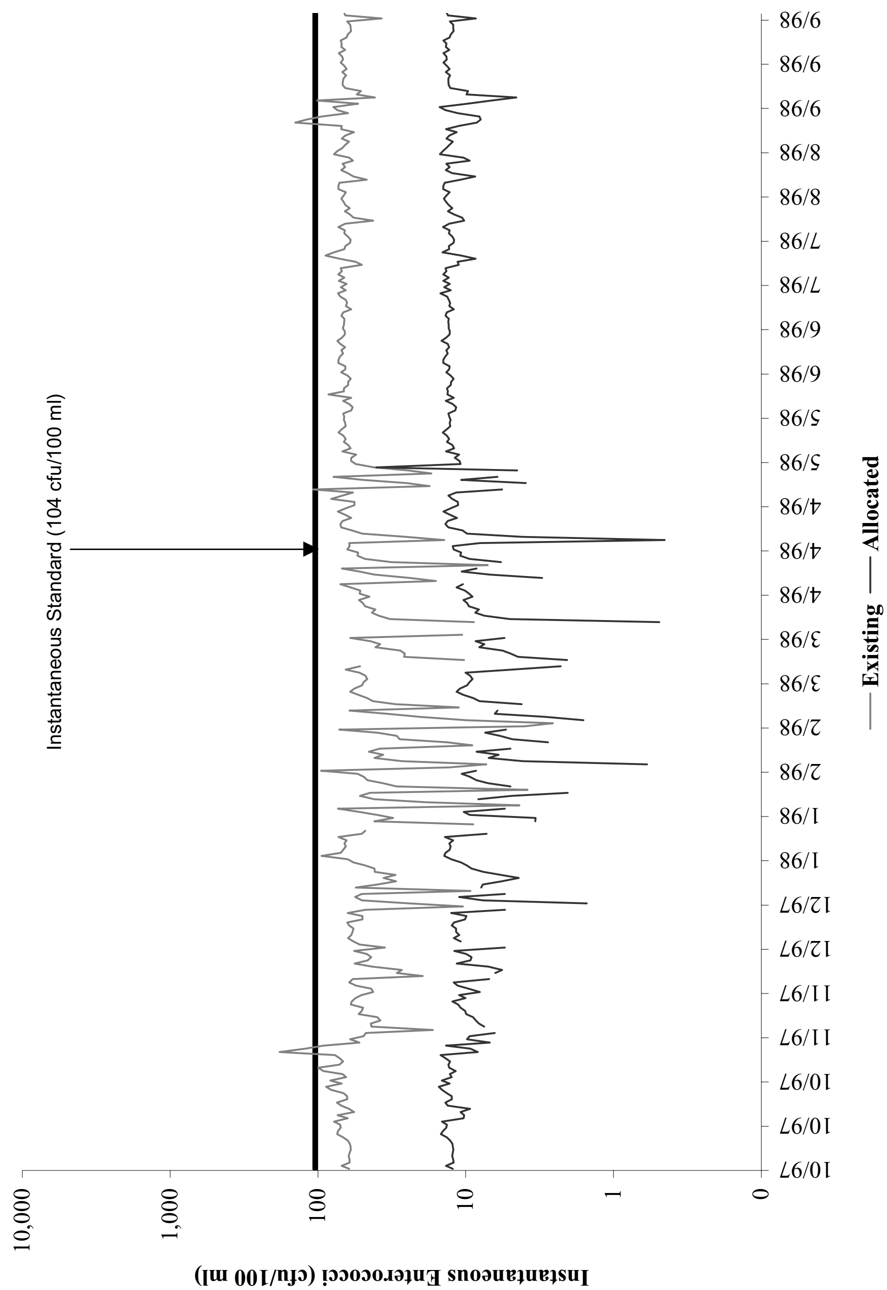

Figure 5.2 Existing and allocation scenarios of daily average *enterococci* concentrations in subwatershed 2, Nansemond River (Upper) impairment outlet.

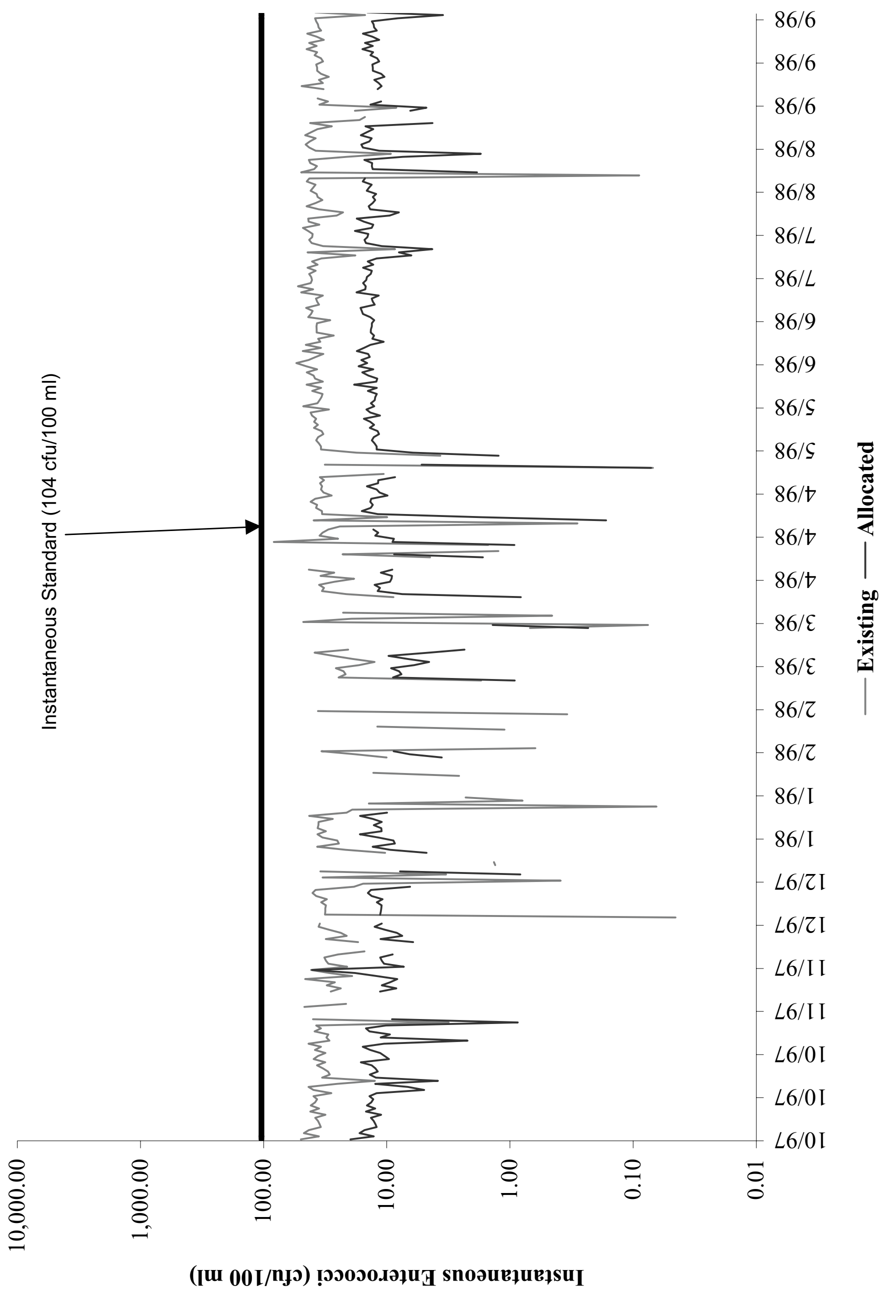

Figure 5.3 Existing and allocation scenarios of daily average *enterococci* concentrations in subwatershed 3, Nansemond River (Lake Meade Dam) impairment outlet.

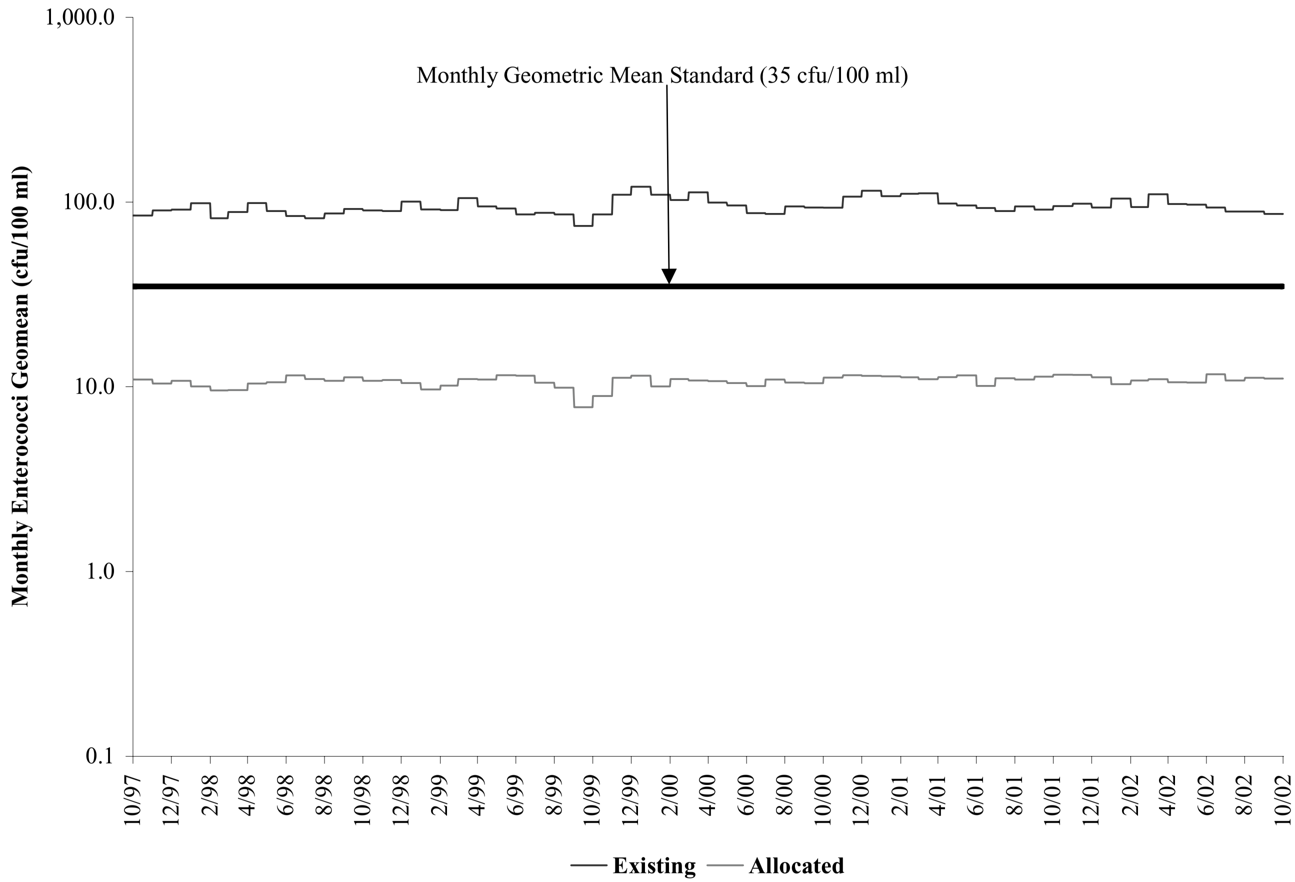

Figure 5.4 Existing and allocation scenarios of 30-month geometric mean *enterococci* concentrations in subwatershed 5, Shingle Creek impairment outlet.

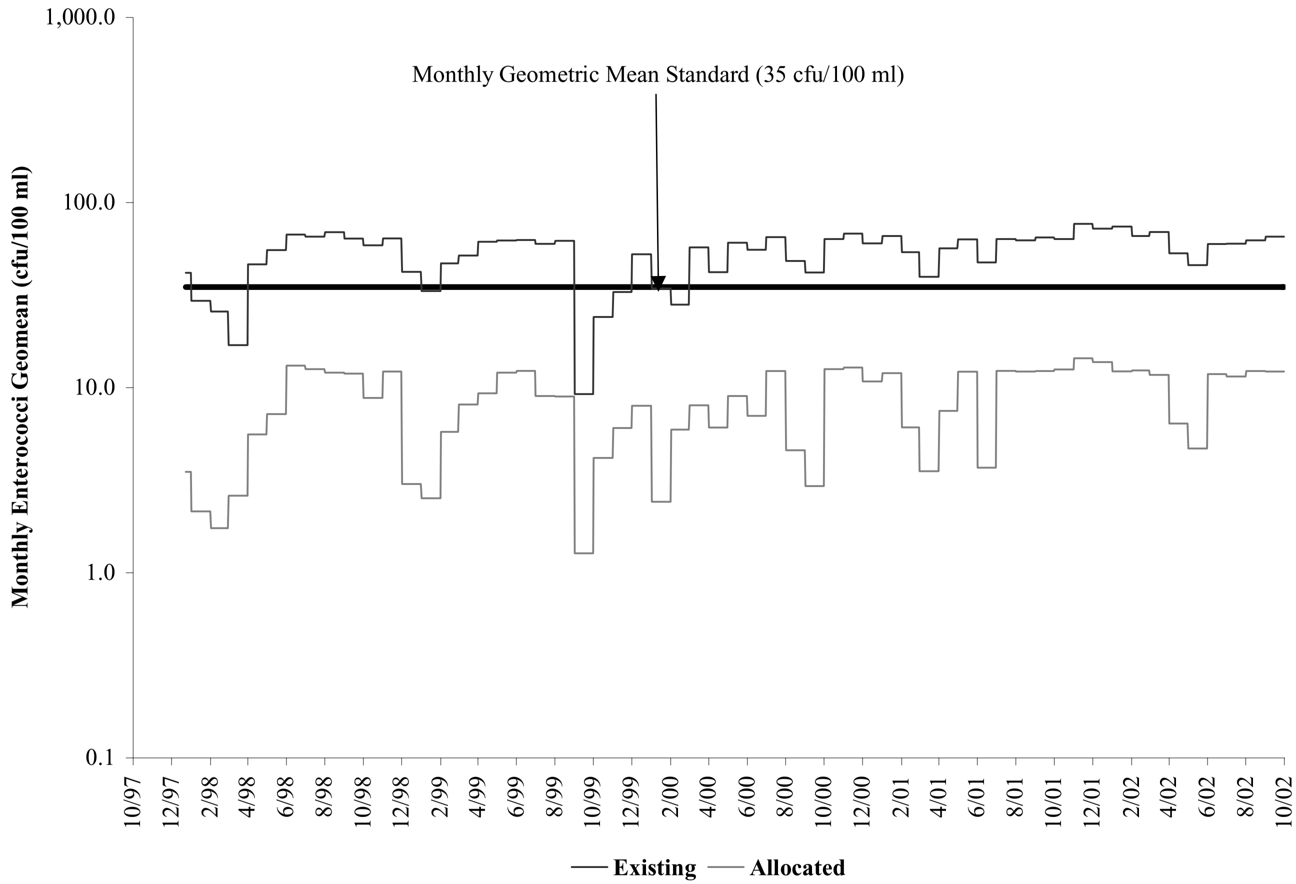

Figure 5.5 Existing and allocation scenarios of 30-month geometric mean *enterococci* concentrations in subwatershed 2, Nansemond River (Upper) impairment.

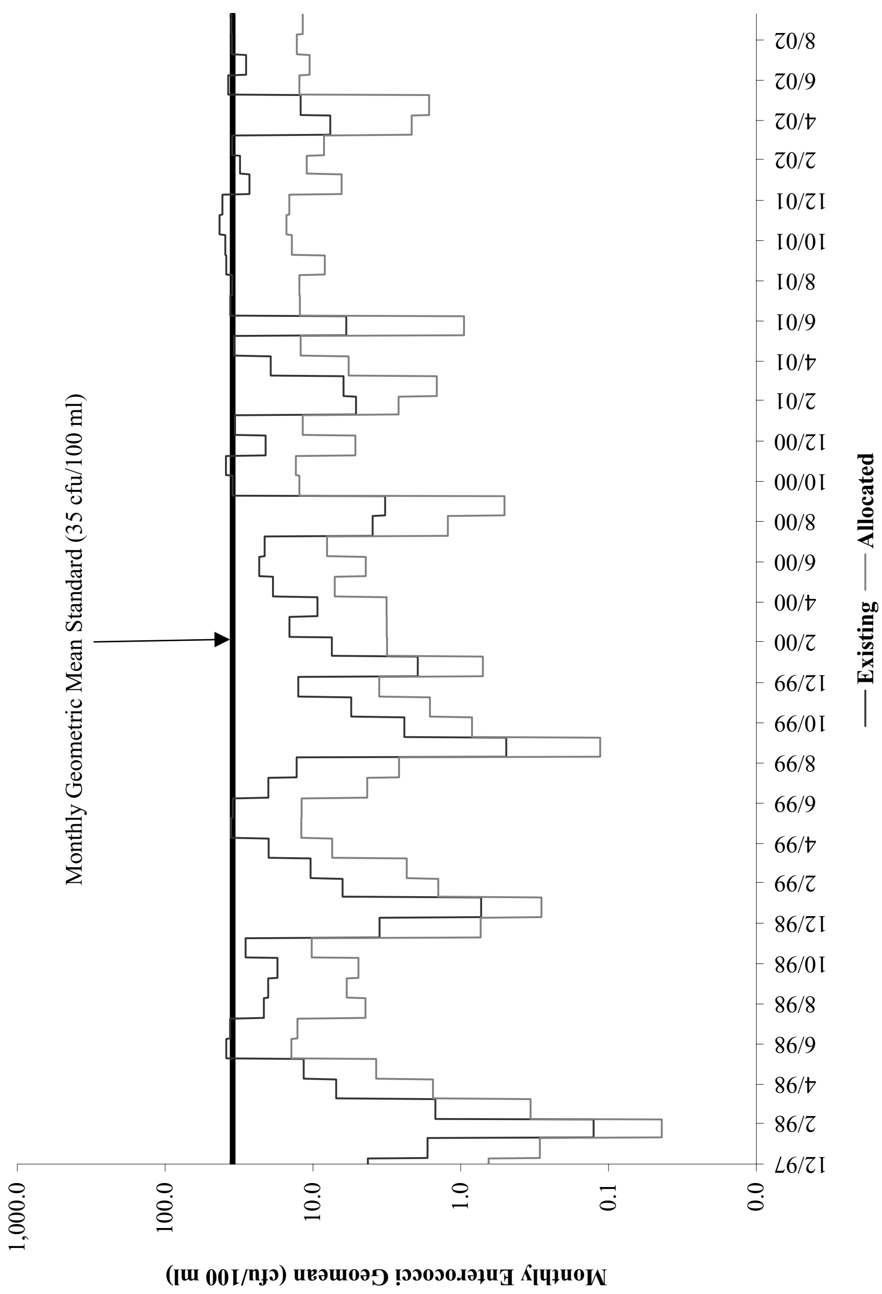

Figure 5.6 Existing and allocation scenarios of 30-month geometric mean *enterococci* concentrations in subwatershed 3, Nansemond River (Lake Meade Dam) impairment.

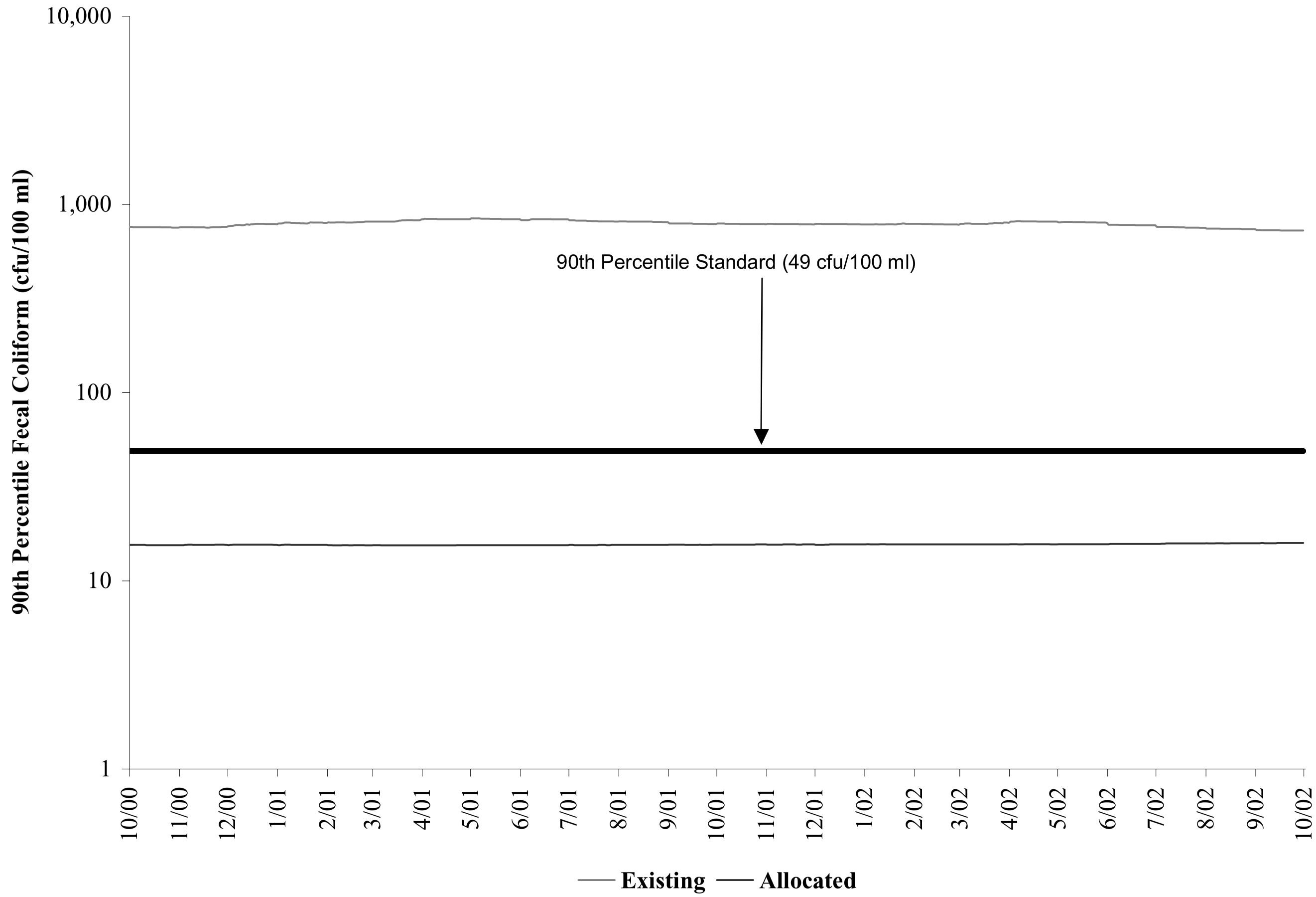

Figure 5.7 Existing and allocation scenarios of the 30-month 90th percentile of fecal coliform concentrations in subwatershed 5, Shingle Creek impairment outlet.

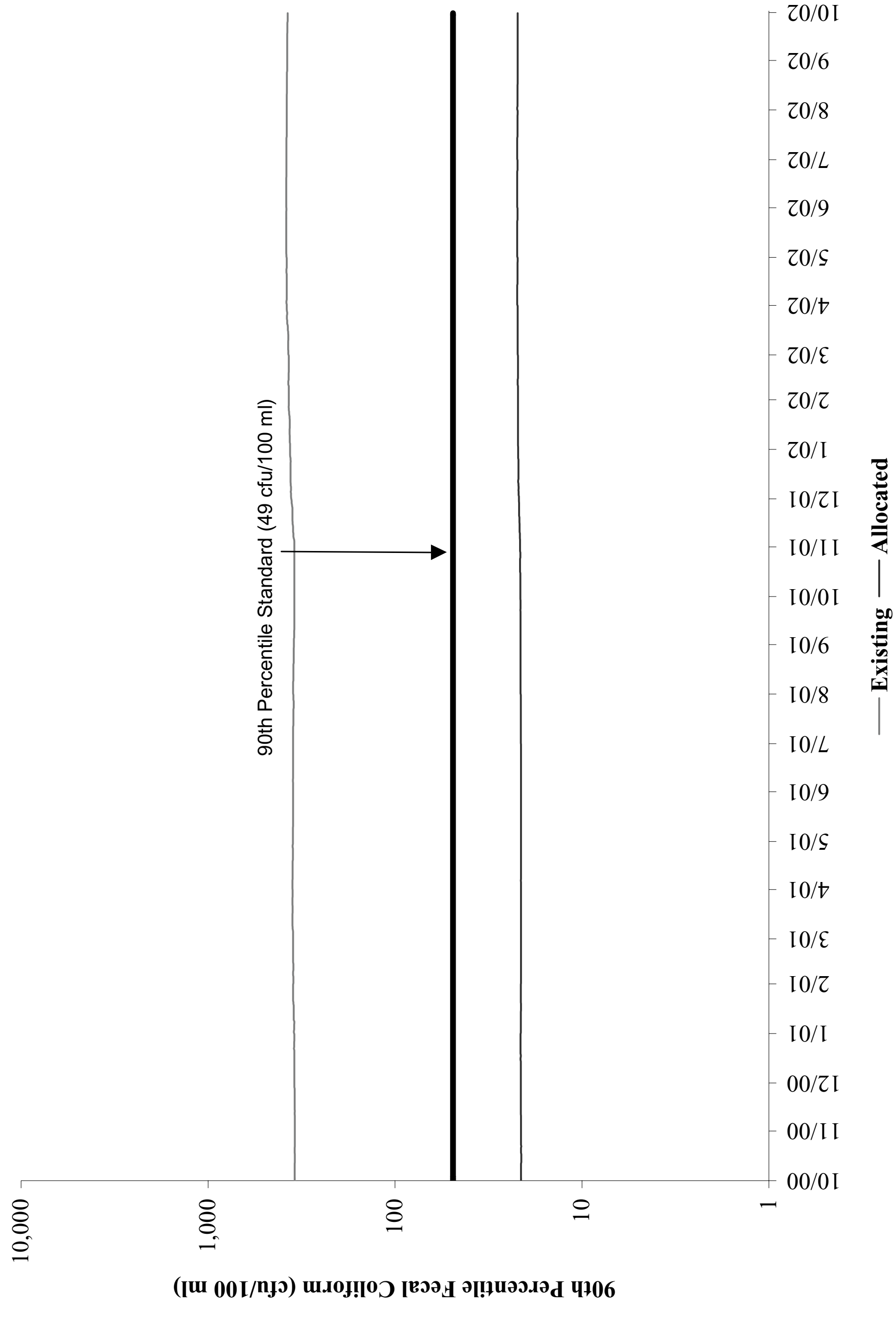

Figure 5.8 Existing and allocation scenarios of the 30-month 90^{th} percentile of fecal coliform concentrations in subwatershed 2, limiting subwatershed to the Nansemond River and Tributaries impairment allocation.

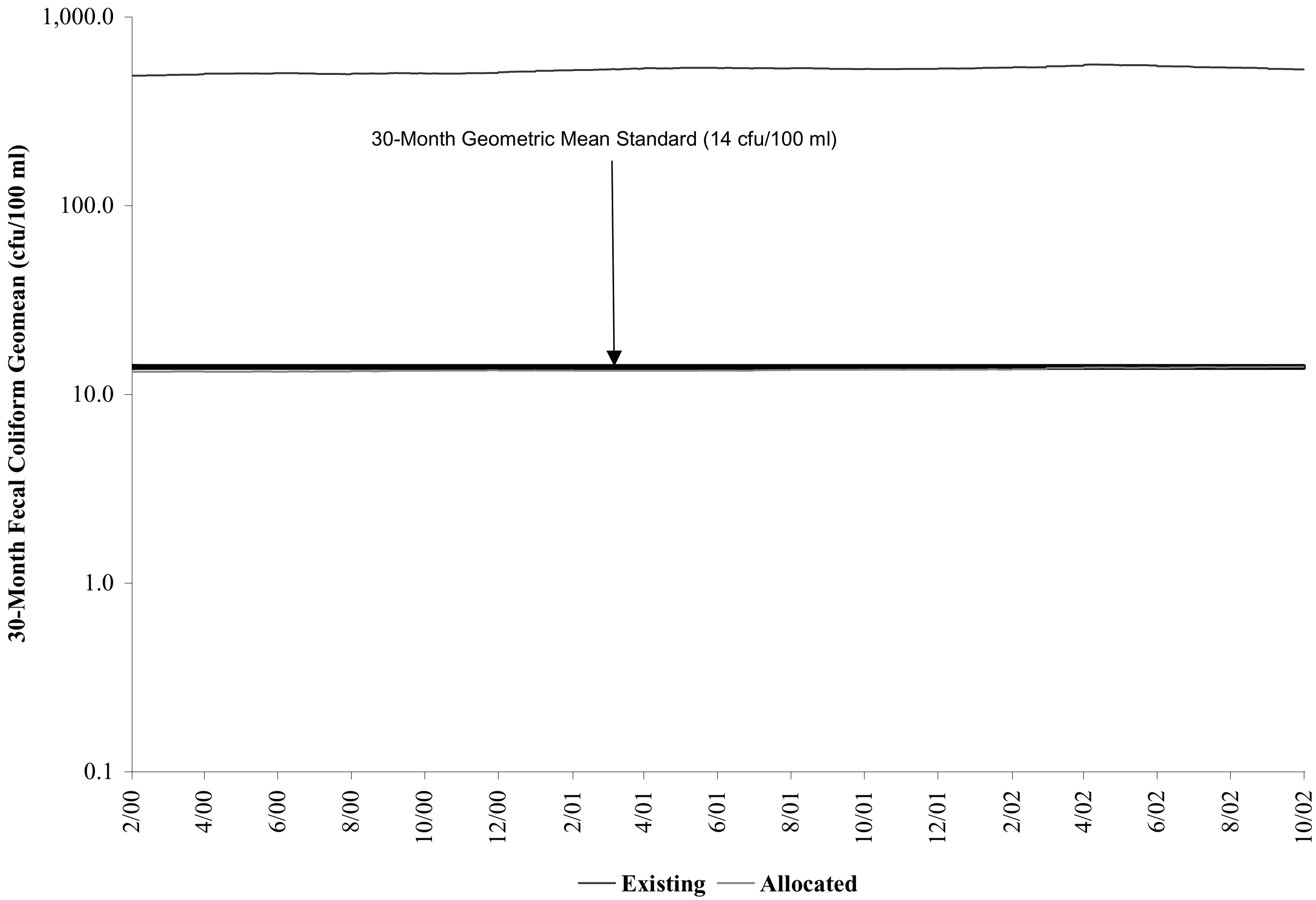

Figure 5.9 Existing and allocation scenarios of the 30-month geometric mean of fecal coliform concentrations in subwatershed 5, Shingle Creek impairment outlet.

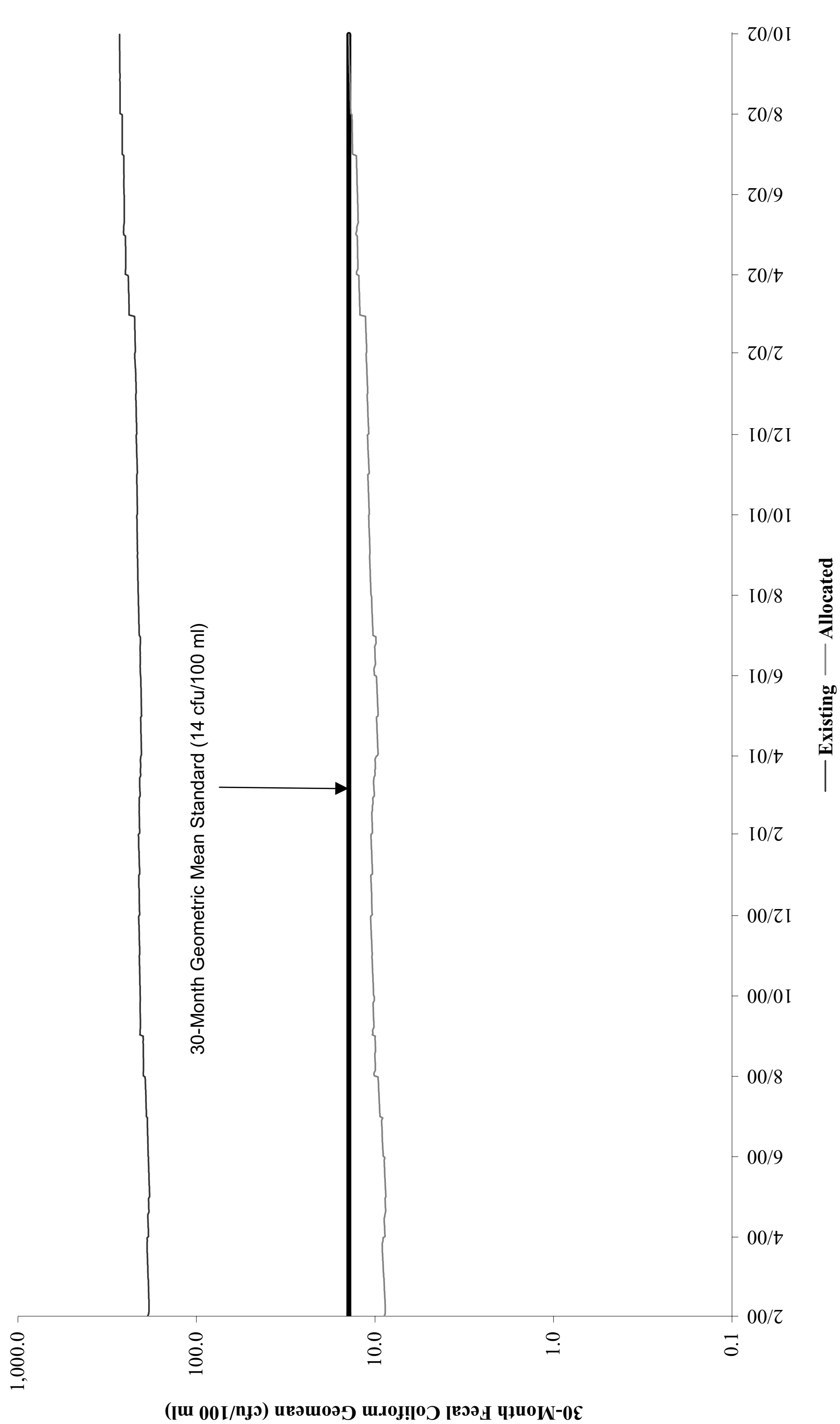

Figure 5.10 Existing and allocation scenarios of the 30-month geometric mean of fecal coliform concentrations in subwatershed 2, limiting subwatershed to the Nansemond River and Tributaries impairment allocation.

Tables 5.5 through 5.8 contain the existing and allocated loads for all the impairments in the Nansemond River watershed, reported as total annual cfu per year from both direct and land-based sources. The percent reduction needed to meet zero percent violations of all water quality standards is given in the final column of these tables.

Table 5.5 Land-based and direct nonpoint source fecal coliform load reductions in the Shingle Creek impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
BarrenTrans	3.91E+11	7.82E+09	98
Commercial	4.46E+12	8.93E+10	98
Forest	1.83E+13	3.66E+11	98
HIR	8.22E+12	8.22E+10	99
LAX	1.95E+12	1.95E+10	99
LIRUrbGrass	1.63E+13	1.63E+11	99
PastureHay	1.73E+14	1.73E+12	99
RowCrop	7.90E+13	7.90E+11	99
Water	0.00E+00	0.00E+00	0
Wetland	9.15E+14	1.83E+13	98
Direct			
Human	4.20E+14	0.00E+00	100
Livestock	4.62E+09	4.62E+07	99
Wildlife	3.95E+13	1.19E+12	97

Table 5.6 Land-based and direct nonpoint source fecal coliform load reductions in the subwatershed 2 impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
BarrenTrans	6.06E+12	1.82E+11	97
Commercial	3.55E+13	1.06E+12	97
Forest	4.54E+14	1.36E+13	97
HIR	3.37E+12	1.35E+11	96
LAX	2.43E+13	9.70E+11	96
LIRUrbGrass	5.59E+13	2.24E+12	96
PastureHay	1.04E+15	4.16E+13	96
RowCrop	7.88E+14	3.15E+13	96
Water	0.00E+00	0.00E+00	0
Wetland	4.84E+14	1.45E+13	97
Direct			
Human	6.41E+14	0.00E+00	100
Livestock	2.34E+10	2.34E+10	0
Wildlife	8.39E+13	3.36E+12	96

Table 5.7 Land-based and direct nonpoint source fecal coliform load reductions in the subwatershed 1,2, 5, 3 impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
BarrenTrans	6.46E+12	1.33E+11	97.9
Commercial	5.04E+13	1.13E+13	77.6
Forest	4.95E+14	3.25E+13	93.4
HIR	1.16E+13	3.63E+11	96.9
LAX	2.94E+13	3.55E+12	87.9
LIRUrbGrass	7.54E+13	4.48E+12	94.1
PastureHay	1.32E+15	1.30E+14	90.2
RowCrop	9.18E+14	6.17E+13	93.3
Water	0.00E+00	0.00E+00	0.0
Wetland	1.89E+15	5.29E+14	72.0
Direct			
Human	7.48E+14	0.00E+00	100
Livestock	2.51E+10	2.51E+10	0
Wildlife	1.08E+14	1.08E+14	0

Table 5.8 Land-based and direct nonpoint source fecal coliform load reductions in the subwatershed 1,2,3,4 5, 6,7 impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
BarrenTrans	1.91E+13	1.20E+13	37.2
Commercial	7.62E+13	2.49E+13	67.3
Forest	9.72E+14	5.09E+14	47.6
HIR	1.29E+13	1.19E+12	90.8
LAX	6.30E+13	3.71E+13	41.1
LIRUrbGrass	1.18E+14	4.59E+13	61.1
PastureHay	4.90E+15	3.71E+15	24.4
RowCrop	3.25E+15	2.39E+15	26.3
Water	0.00E+00	0.00E+00	0.0
Wetland	2.59E+15	1.23E+15	52.6
Direct			
Human	1.03E+15	0.00E+00	100
Livestock	7.43E+10	7.43E+10	0
Wildlife	1.68E+14	1.68E+14	0

Table 5.9 is the TMDL table, which gives the number of cfu of *E. coli* that can reach the stream in a given year, and still meet existing water quality standards. These figures are broken up into Waste Load Allocation (WLA), or the portion of fecal coliform that may come from permitted discharge sources and Load Allocation (LA), or the portion of fecal coliform that may come from the non-permitted nonpoint sources existing in the watershed.

Suffolk City currently has a Municipal Separate Storm Sewer System (MS4) permit with multiple outfalls (VAR040044). For this report, it was assumed that all impervious area in the downtown Suffolk area drains to an MS4 outfall to the Nansemond River. This area was limited to the impervious area in subwatersheds 1, 2, and 5, which was estimated as 1,577 acres. All fecal coliform and *enterococci* from this area was allocated to the MS4 (VAR040044) in the TMDL tables. A Master Drainage Study for City of Suffolk is currently being developed. This study will determine the drainage area of each outfall. At the time when this study is completed, the *enterococci* and fecal coliform final TMDLs may need adjusting.

The loads from point sources permitted to discharge fecal bacteria to a water body were increased by five (5) times to show the resulting *enterococci* and fecal coliform TMDL final loads with a human population increase. These TMDL tables are shown in Appendix C (Tables C-1 and C-2).

Table 5.9 Average annual *enterococci* bacterial loads (cfu/year) modeled after TMDL allocation in the Nansemond River watershed impairments.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Shingle Creek (subwatershed 5)	2.19E+10	1.05E+13		1.05E+13
VAR040044	*2.19E+10*			
Nansemond River (Upper) (subwatersheds 1,2,5)	9.99E+10	5.80E+13		5.81E+13
VA0021709	*2.18E+09*			
VA0086134	*3.14E+10*		*Implicit*	
VAR040044	*6.63E+10*			
Nansemond River (Lake Meade Dam) (subwatersheds 1,2,3,5)	9.99E+10	4.26E+13		4.27E+13
VA0021709	*2.18E+09*			
VA0086134	*3.14E+10*			
VAR040044	*6.63E+10*			

Table 5.10 Average annual fecal coliform bacterial loads (cfu/year) modeled after TMDL allocation in the Nansemond River watershed impairments.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Shingle Creek (subwatershed 5)	2.78E+09	1.05E+13	*Implicit*	1.05E+13
VAR040044	*2.78E+09*			
Nansemond R. and Tributaries (all subwatersheds)	3.89E+10	9.47E+12		9.51E+12
VA0021709	*1.06E+09*			
VA0027138	*2.54E+09*			
VA0027146	*2.26E+09*			
VA0069302	*1.88E+09*			
VA0086134	*1.53E+10*			
VAG403000	*1.06E+08*			
VAR040044	*1.58E+10*			

6. IMPLEMENTATION

Once a TMDL has been approved by the EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources in the stream (see section 6.4.2). For point sources, all new or revised Virginia Pollutant Discharge Elimination System (VPDES) National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the TMDL WLA pursuant to 40 CFR§122.44 (d)(1)(vii)(B) and must be submitted to the EPA for approval. The measures for nonpoint source reductions, which can include the use of better treatment technology and the installation of BMPs, are implemented in an iterative process that is described along with specific BMPs in the Implementation Plan (IP). The process for developing an IP has been described in the *Guidance Manual for Total Maximum Daily Load Implementation Plans* published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf. With successful completion of IPs, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

6.1 Staged Implementation

In general, Virginia intends for the required bacteria reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL IP. While specific goals for BMP implementation will be established as part of the IP development, the following Stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

6.2 Stage 1 Scenarios

The goal of the Stage 1 scenarios is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the single sample maximum criterion (104 cfu/100mL *enterococci*) are less than 10 percent. The Stage 1 scenarios were generated with the same model setup as was used for the TMDL allocation scenarios. The Stage 1 scenario for all impairments in this report was 100% elimination of direct human sources. Details of this scenario and the direct human sources for each impairment area in Table 5.1 through 5.4 and Tables 5.5 through 5.8.

6.3 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to ongoing water quality improvement efforts aimed at restoring water quality in Virginia's streams. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of the Tributary Strategy for the James River basin. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. Up-to-date information on the tributary strategy implementation process can be found at the tributary strategy web site under:

http://www.naturalresources.virginia.gov/WaterQuality/FinalizedTribStrats/James.pdf

6.4 Reasonable Assurance for Implementation

6.4.1 Follow-Up Monitoring

Following the development of the TMDL, the VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring program. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with Guidance Memo No. 03-2004 (VADEQ, 2003), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, in cooperation with the VADCR staff, the IP Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30 of each year.

VADEQ staff, in cooperation with VADCR staff, the IP Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in the VADEQ's standard monitoring plan. Ancillary monitoring by citizens, watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established Quality Assurance /Quality Control (QA/QC) guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request that the monitoring managers in each regional office increase the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/.

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or TMDL IP has been completed), the VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc.) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one-year period.

6.4.2 Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL IPs as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. The EPA also requires that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to the EPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the State Water Control Board (SWCB) to "develop and implement a plan to achieve fully supporting status for impaired waters" (section 62.1-44.19.7). WQMIRA also establishes that the IP shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary, and the associated costs, benefits and environmental impacts of addressing the impairments. The EPA outlines the minimum elements of an approvable IP in its 1999 *Guidance for Water Quality-Based Decisions: The TMDL Process*. The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, and monitoring plans and milestones for attaining water quality standards.

For the implementation of the WLA component of the TMDL, the Commonwealth intends to utilize the VPDES program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process and, with the exception of stormwater related permits, permitted sources are not usually addressed during the development of a TMDL IP.

For the implementation of the TMDL's LA component, a TMDL IP addressing the WQMIRA requirements, at a minimum, will be developed. The MS4s are covered by

NPDES permits and are an exception; they are expected to be included in TMDL implementation plans, as described in the stormwater permit section below.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL IP. Regional and local offices of VADEQ, VADCR, and other cooperating agencies are technical resources to assist in this endeavor.

In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the state's Water Quality Management Plans (WQMPs). Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL Implementation Plans developed within a river basin.

VADEQ staff will present both EPA-approved TMDLs and TMDL IPs to the SWCB for inclusion in the appropriate WQMP, in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as is the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on the VADEQ's web site under http://www.deq.state.va.us/tmdl/pdf/ppp.pdf

6.4.3 Stormwater Permits

VADEQ and VADCR coordinate separate State programs that regulate the management of pollutants carried by stormwater runoff. The VADEQ regulates stormwater discharges associated with "industrial activities", while the VADCR regulates storm water discharges from construction sites, and from MS4s.

EPA approved the VADCR's VPDES stormwater program on December 30, 2004. The VADCR's regulations became effective on January 29, 2005. The VADEQ is no longer the regulatory agency responsible for administration and enforcement of the VPDES MS4 and construction storm water permitting programs. More information is available on the VADCR's web site through the following link: http://www.dcr.virginia.gov/sw/vsmp

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is VADCR's Virginia Stormwater Management Program (VSMP) Permit Regulation (4 VAC 50-60-10 et. seq). Section 4VAC 50-60-380 describes the requirements for stormwater discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when:…(2) Numeric effluent limitations are infeasible,…".

Part of the Nansemond River watershed is covered by VAR040044 for small municipal separate storm sewer systems (MS4s) owned by Suffolk City. The permits state, under Part II.A., that the

"permittee must develop, implement, and enforce a stormwater management program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Clean Water Act and the State Water Control Law."

The permit also contains a TMDL clause that states:

"If a TMDL is approved for any waterbody into which the small MS4 discharges, the Board will review the TMDL to determine whether the TMDL includes requirements for control of stormwater discharges. If discharges from the MS4 are not meeting the TMDL allocations, the Board will notify the permittee of that finding and may require that the Stormwater Management Program required in Part II be modified to implement the TMDL within a timeframe consistent with the TMDL." ("Board" means the Soil and Water Conservation Board)

For MS4/VSMP general permits, the Commonwealth expects the permittee to specifically address the TMDL wasteload allocations for stormwater through the implementation of programmatic BMPs. BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Office of Water, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its stormwater management program to achieve the TMDL wasteload allocation. However, only failing to implement the programmatic BMPs identified in the modified stormwater management program would be considered a violation of the permit. The VADEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs (see section 7.4.5). At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis (UAA). Any changes to the TMDL resulting from water quality standards change on the Nansemond River would be reflected in the permit.

Wasteload allocations for stormwater discharges from storm sewer systems covered by a MS4 permit will be addressed in TMDL IPs. An implementation plan will identify types of corrective actions and strategies to obtain the wasteload allocation for the pollutant causing the water quality impairment. Permittees need to participate in the development of TMDL IPs since recommendations from the process may result in modifications to the stormwater management plan in order to meet the TMDL.

Additional information on Virginia's Stormwater Management program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.dcr.virginia.gov/sw/stormwat.htm.

6.4.4 Implementation Funding Sources

Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the IP in accordance with the *Guidance Manual for Total Maximum Daily Load Implementation Plans*. Potential sources for implementation may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program, Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water

Quality Improvement Fund, tax credits, and landowner contributions. The *Guidance Manual for Total Maximum Daily Load Implementation Plans* also contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

6.4.5 Attainability of Primary Contact Recreational Use

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. These streams may not be able to attain standards without some reduction in wildlife load.

With respect to these potential reductions in bacteria loads attributed to wildlife, Virginia and the EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. However, if bacteria levels remain high and localized overabundant populations of wildlife are identified as the source, then measures to reduce such populations may be an option if undertaken in consultation with the Department of Game and Inland Fisheries (DGIF) or the United States Fish and Wildlife Service (USFWS). Additional information on DGIF's wildlife programs can be found at http://www.dgif.virginia.gov/hunting/va_game_wildlife/. While managing such overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address the overall issue of attainability of the primary contact criteria, during its latest triennial water quality standards review Virginia proposed a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia SWCB adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria became effective on February 12, 2004 and can be found at http://www.deq.virginia.gov/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable BMPs for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a UAA. All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and the EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/WQS03AUG.pdf

The process to address potentially unattainable reductions based on the above is as follows: First is the development of a Stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the Stage 1 scenario are targeted primarily at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife (except for cases of nuisance populations). During the implementation of the Stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in section 6.1 above. The VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the Stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, and no additional cost-effective and reasonable BMPs can be identified, a UAA may be initiated with the goal of re-designating the stream for secondary contact recreation.

7. PUBLIC PARTICIPATION

The development of the Nansemond River TMDL greatly benefited from public involvement. Table 7.1 details the public participation throughout the project. The first public meeting was held at the Morgan Memorial Library in Suffolk, Virginia on February 21, 2006 to discuss the process for TMDL development. Eight people attended the meeting, including 1 landowner, 3 consultants, and 4 agency representatives. The meeting was publicized in the *Virginia Register* and the local newspaper.

The final public meeting was held on April 10, 2006 at the Morgan Memorial Library in Suffolk, Virginia. The meeting was publicized with notices in the *Virginia Register* and on the VADEQ website. There was a 30-day public comment period.

Table 7.1 Public participation during TMDL development for the Nansemond River watershed.

Date	Location	Attendance[1]	Type	Format
2/21/2006	Morgan Memorial Library 443 W. Washington St. Suffolk, VA	8	1st public	Open to public at large
4/10/2006	Morgan Memorial Library 443 W. Washington St. Suffolk, VA	6	Final public	Open to public at large

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

Public participation during the implementation plan development process will include the formation of a stakeholders' committee as well as open public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. A stakeholders' committee will have the express purpose of formulating the TMDL Implementation Plan. The major stakeholders were identified during the development of this TMDL. The committee will consist of, but not be limited to, representatives from VADEQ, VADCR, and local governments. This committee will have the responsibility for identifying corrective actions that are founded in practicality, establishing a time line to insure expeditious implementation, and setting measurable goals and milestones for attaining water quality standards.

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GLOSSARY

Note: All entries in italics are taken from USEPA (1998).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Cause. 1. That which produces an effect (a general definition).
2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition). (2)

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition. *Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also Respiration.*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge permits (under NPDES). *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

E. Coli (Escherichia coli) – one of the groups of fecal coliform bacteria associated with the digestive tract of warm-blooded animals used as indicator organisms (organisms indicating presence of pathogens) to detect the presence of pathogenic bacteria in the water.

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Enterococci – a subgroup of fecal streptococcal bacteria associated with the digestive tract of warm-blooded animals used as indicator organisms (organisms indicating presence of pathogens) to detect the presence of pathogenic bacteria in the water.

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Existing use. *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph. *A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrology. *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

Interflow. Runoff that travels just below the surface of the soil.

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mathematical model. *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Model. Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

MS4. Municipal Separate Stormwater Sewer System.

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Nonpoint source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Numeric targets. *A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

Peak runoff. *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Raw sewage. Untreated municipal sewage.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient. *A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles.

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer*. A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Simulation. *The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor. (2)

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (*e.g.* 200 cfu/100 ml geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (*i.e.* a low p-value indicates statistical significance).

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Tidal Prism Model – a steady state model that uses mass balance equations to calculate the volume of water in a tidal water system and the associated pollutant load (*e.g.,* fecal coliform concentration).

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (*e.g*. 15-minutes, 1-hour, 1-day).

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to remediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

TRC. Total Residual Chlorine. A measure of the effectiveness of chlorinating treated waste water effluent.

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Urban Runoff. Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.*

Wastewater treatment. *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality criteria. *Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

APPENDIX A

FREQUENCY ANALYSIS OF WATER QUALITY SAMPLING DATA

Figure A.1 Frequency analysis of fecal coliform concentrations at station 2-NAN000.20 in the Nansemond River impairment for the period June 1983 to June 2002.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

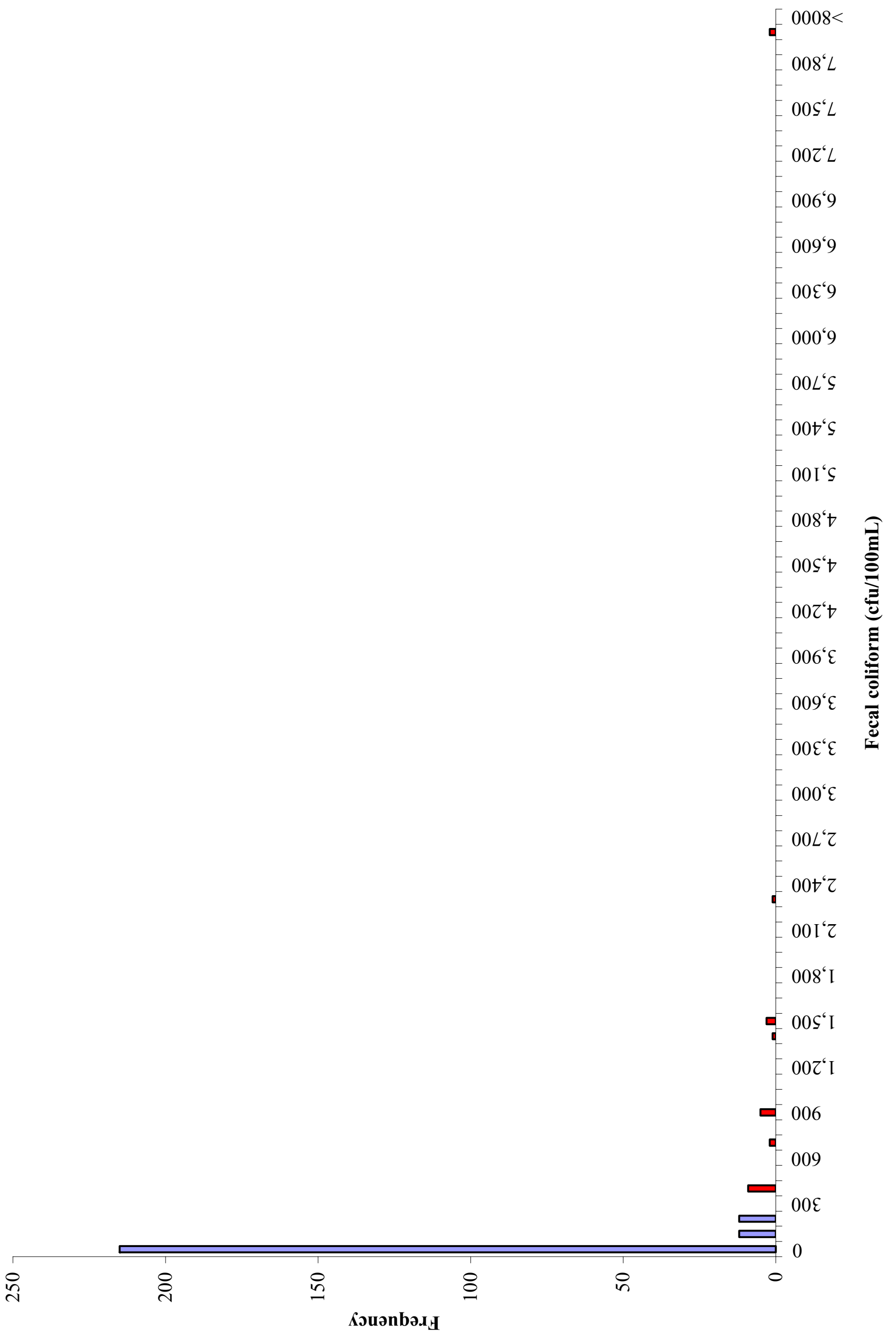

Figure A.2 Frequency analysis of fecal coliform concentrations at station 2-NAN002.77 in the Nansemond River impairment for the period January 1980 to June 2002.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

Figure A.3 Frequency analysis of fecal coliform concentrations at station 2-NAN002.88 in the Nansemond River impairment for the period June 1983 to June 1985.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

Figure A.4 Frequency analysis of fecal coliform concentrations at station 2-NAN005.82 in the Nansemond River impairment for the period June 1983 to June 2002.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

Figure A.5 Frequency analysis of fecal coliform concentrations at station 2-NAN007.89 in the Nansemond River impairment for the period June 1983 to June 2002.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

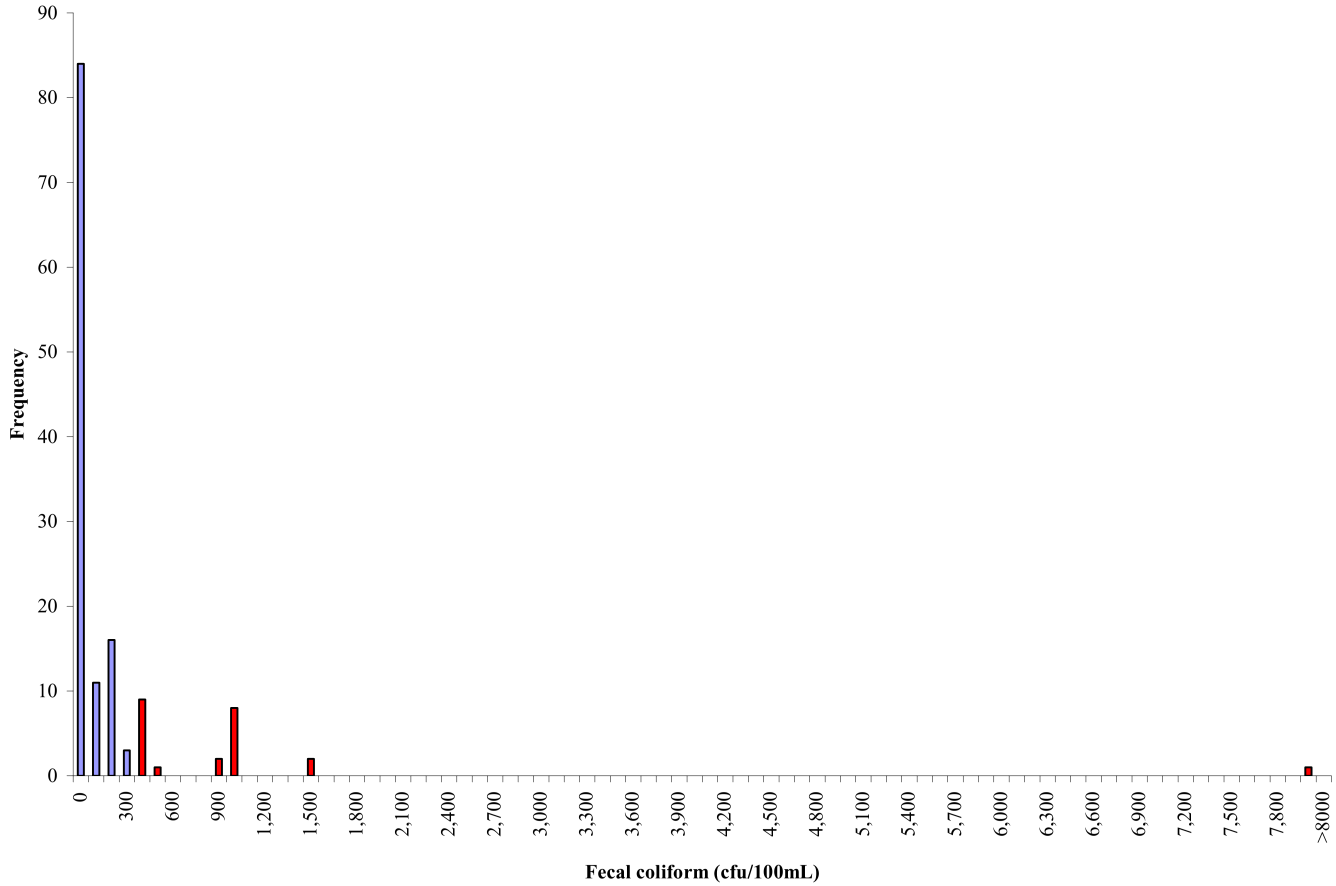

Figure A.6 Frequency analysis of fecal coliform concentrations at station 2-NAN010.69 in the Nansemond River impairment for the period June 1983 to June 2002.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

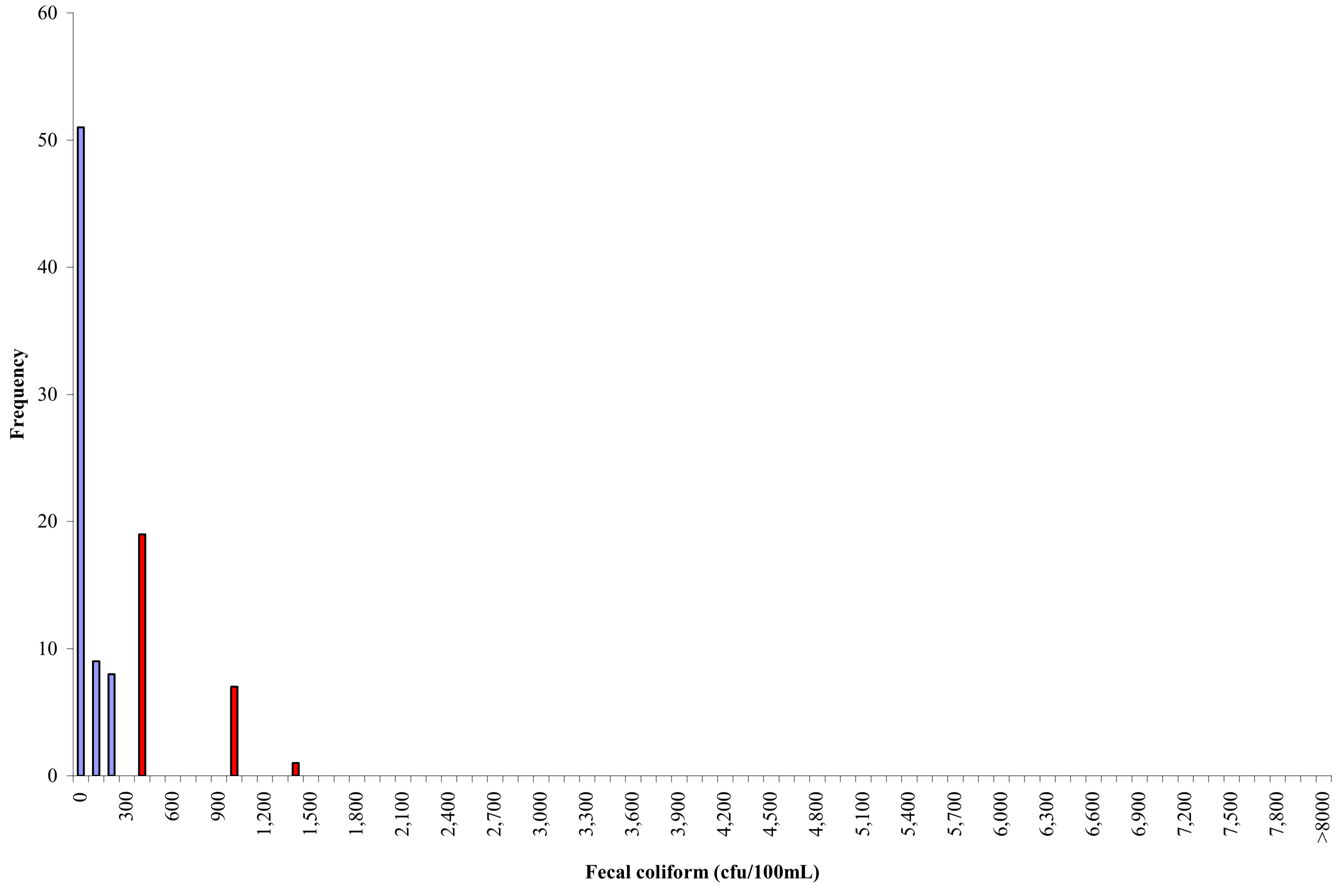

Figure A.7 Frequency analysis of fecal coliform concentrations at station 2-NAN012.53 in the Nansemond River impairment for the period June 1983 to March 1991.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

Figure A.8 Frequency analysis of fecal coliform concentrations at station 2-NAN013.50 in the Nansemond River impairment for the period February 1996 to June 2002.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

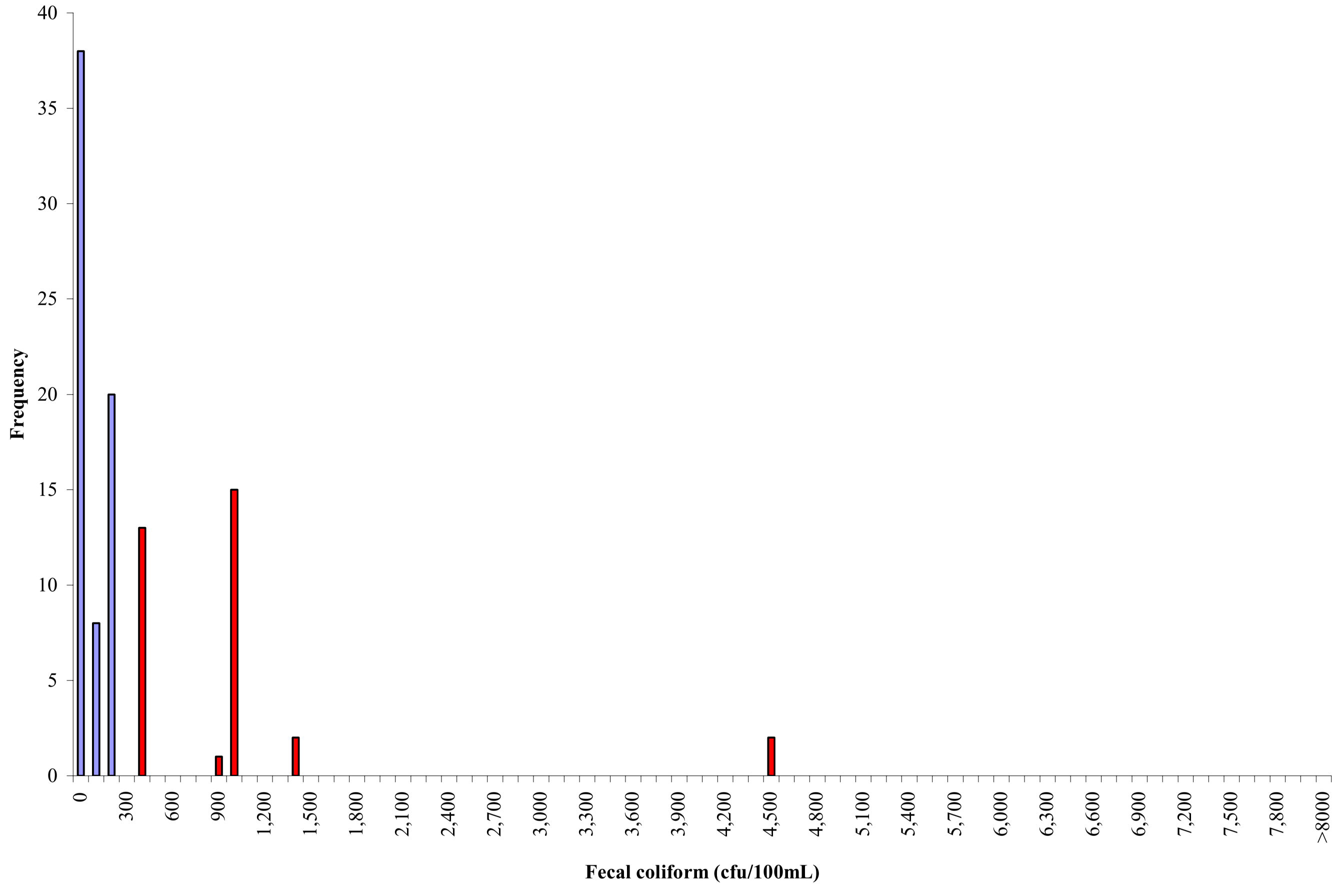

Figure A.9 Frequency analysis of fecal coliform concentrations at station 2-NAN014.96 in the Nansemond River impairment for the period June 1983 to March 1991.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

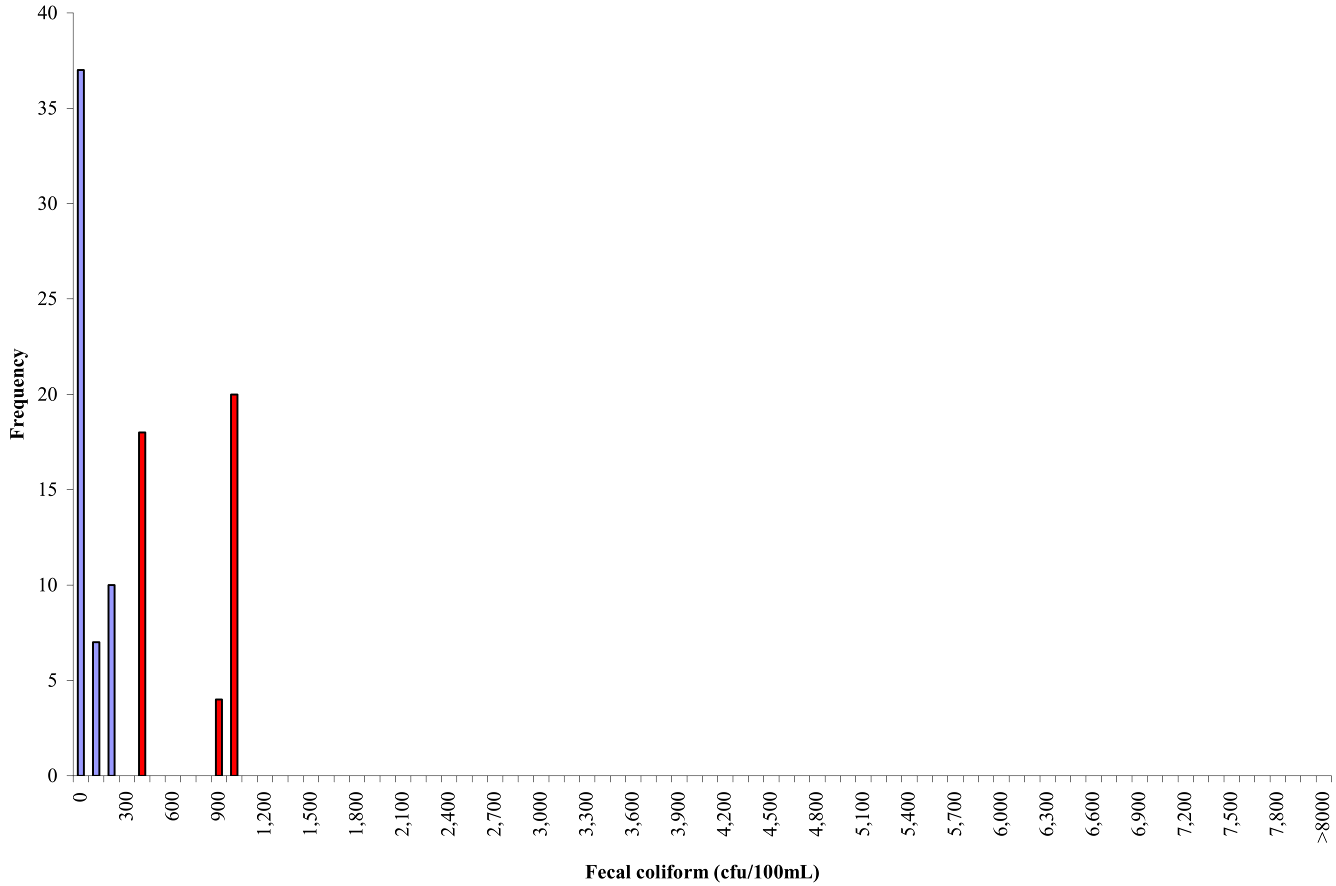

Figure A.10 Frequency analysis of fecal coliform concentrations at station 2-NAN016.07 in the Nansemond River impairment for the period June 1983 to March 1991.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

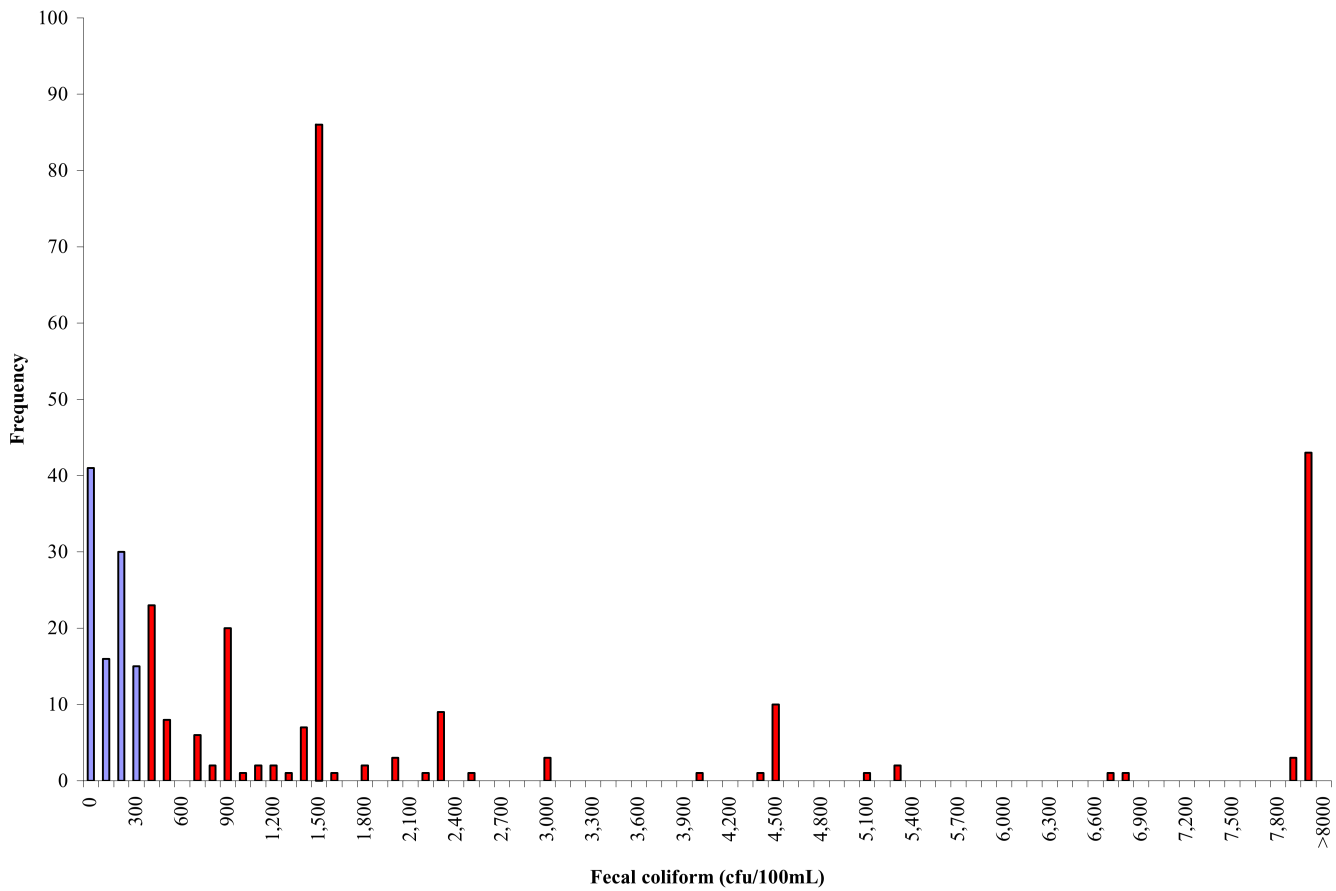

Figure A.11 Frequency analysis of fecal coliform concentrations at station 2-NAN019.14 in the Nansemond River impairment for the period January 1980 to October 2005.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

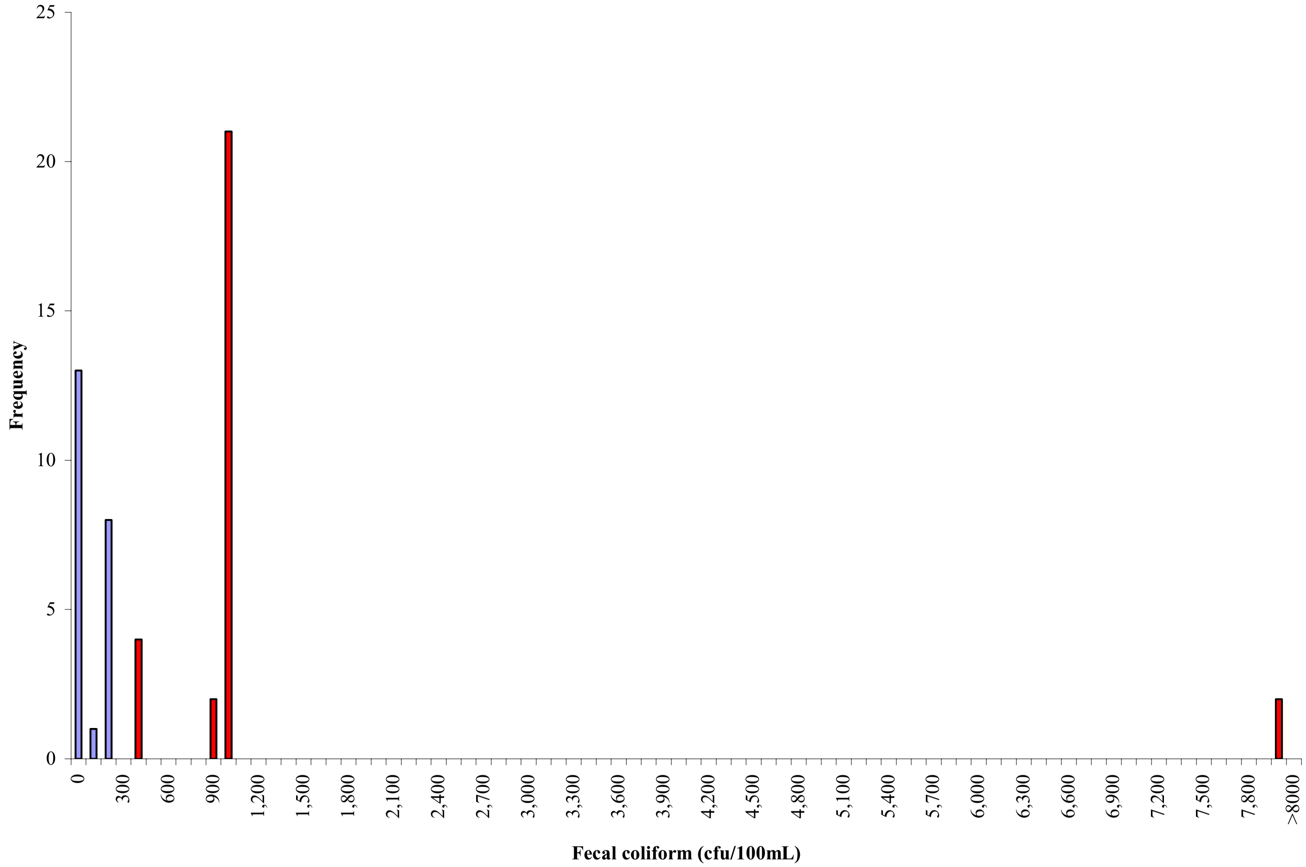

Figure A.12 Frequency analysis of fecal coliform concentrations at station 2-NAN019.73 in the Nansemond River impairment for the period June 1983 to October 1989.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

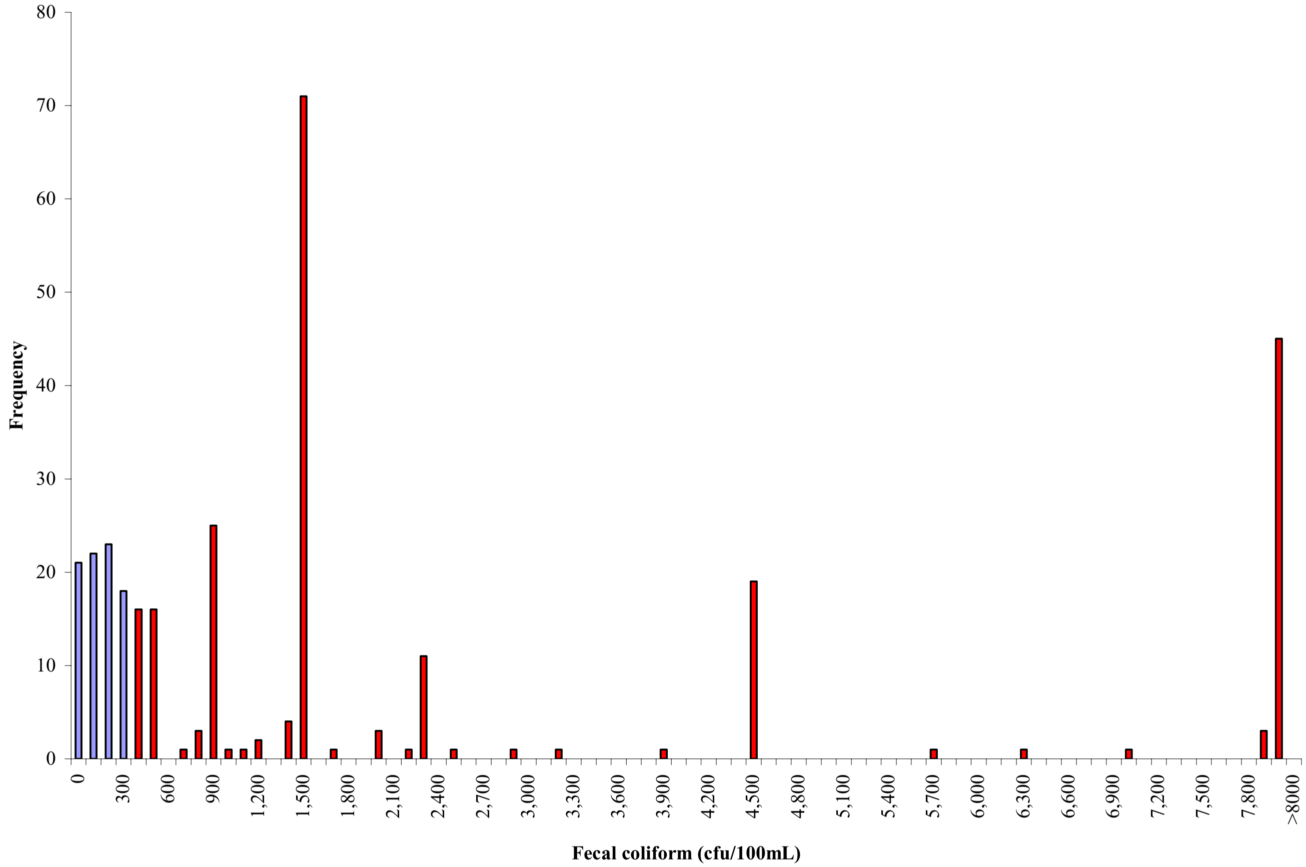

Figure A.13 Frequency analysis of fecal coliform concentrations at station 2-SGL001.00 in the Shingle Creek impairment for the period January 1980 to October 2005.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

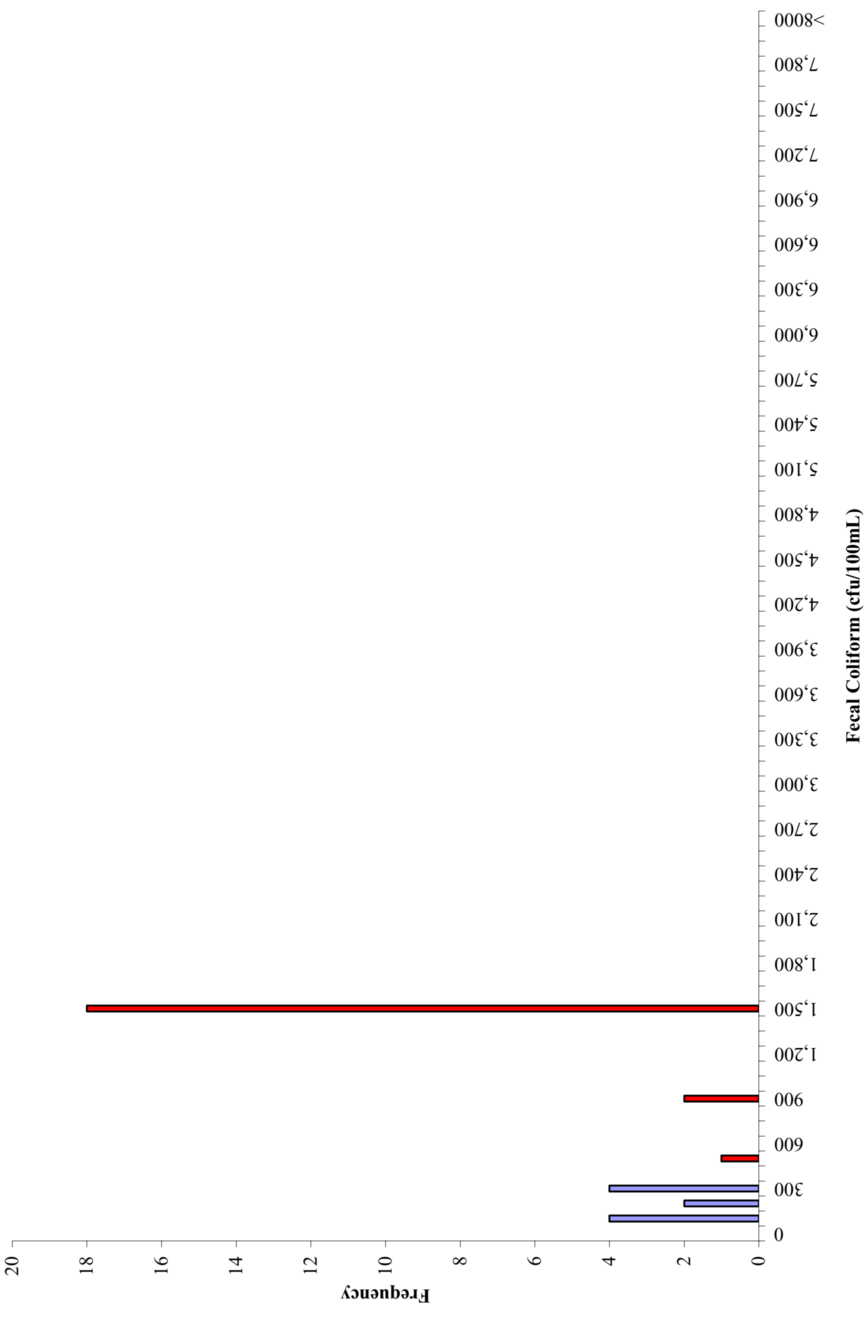

Figure A.14 Frequency analysis of fecal coliform concentrations at station 2-SGL001.50 in the Shingle Creek impairment for the period December 1997 to August 2000.

*Red indicates a value which violates the listing standard of 400 cfu/100mL.

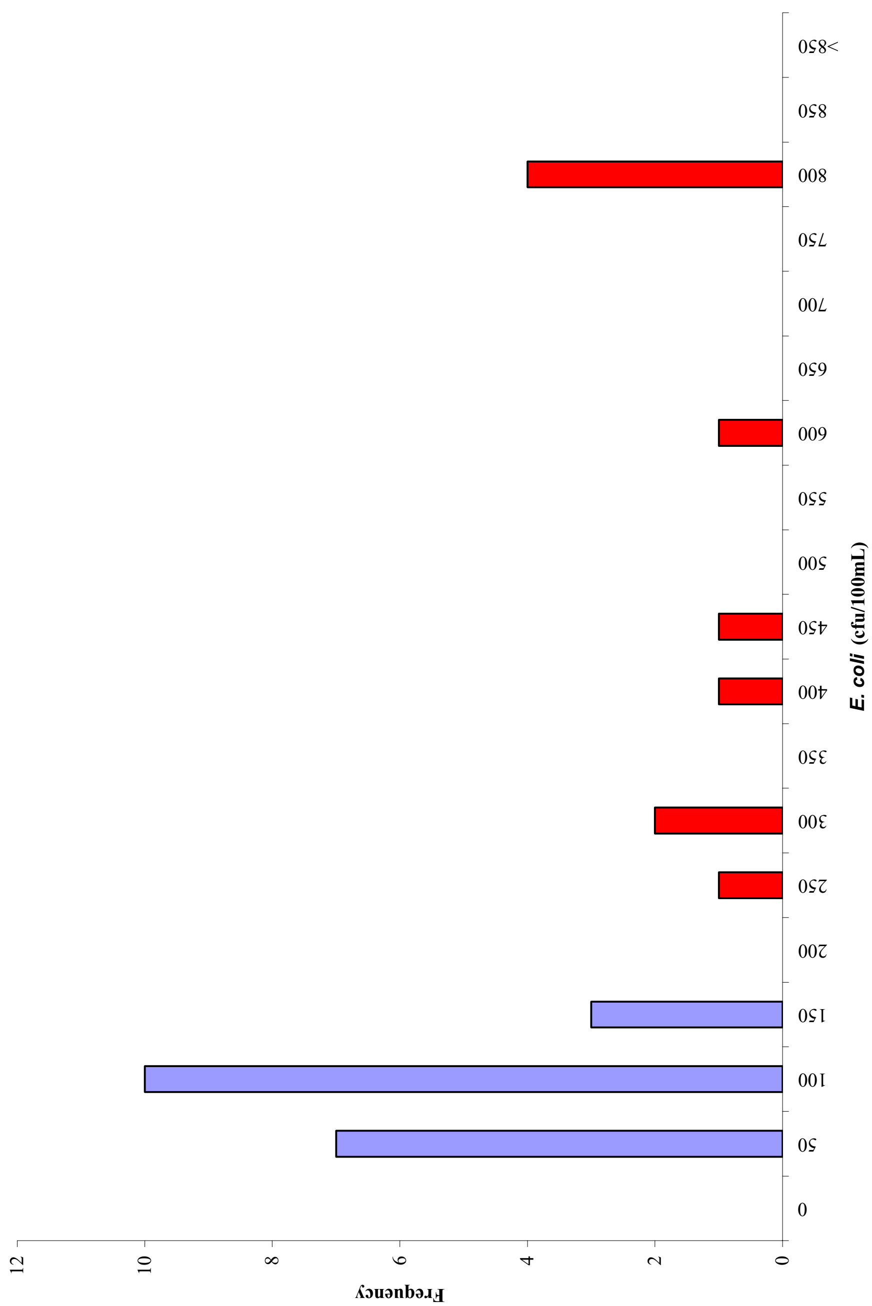

Figure A.15 Frequency analysis of *E. coli* concentrations at station 2-NAN019.14 in the Nansemond River impairment for the period March 2000 to April 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100mL.

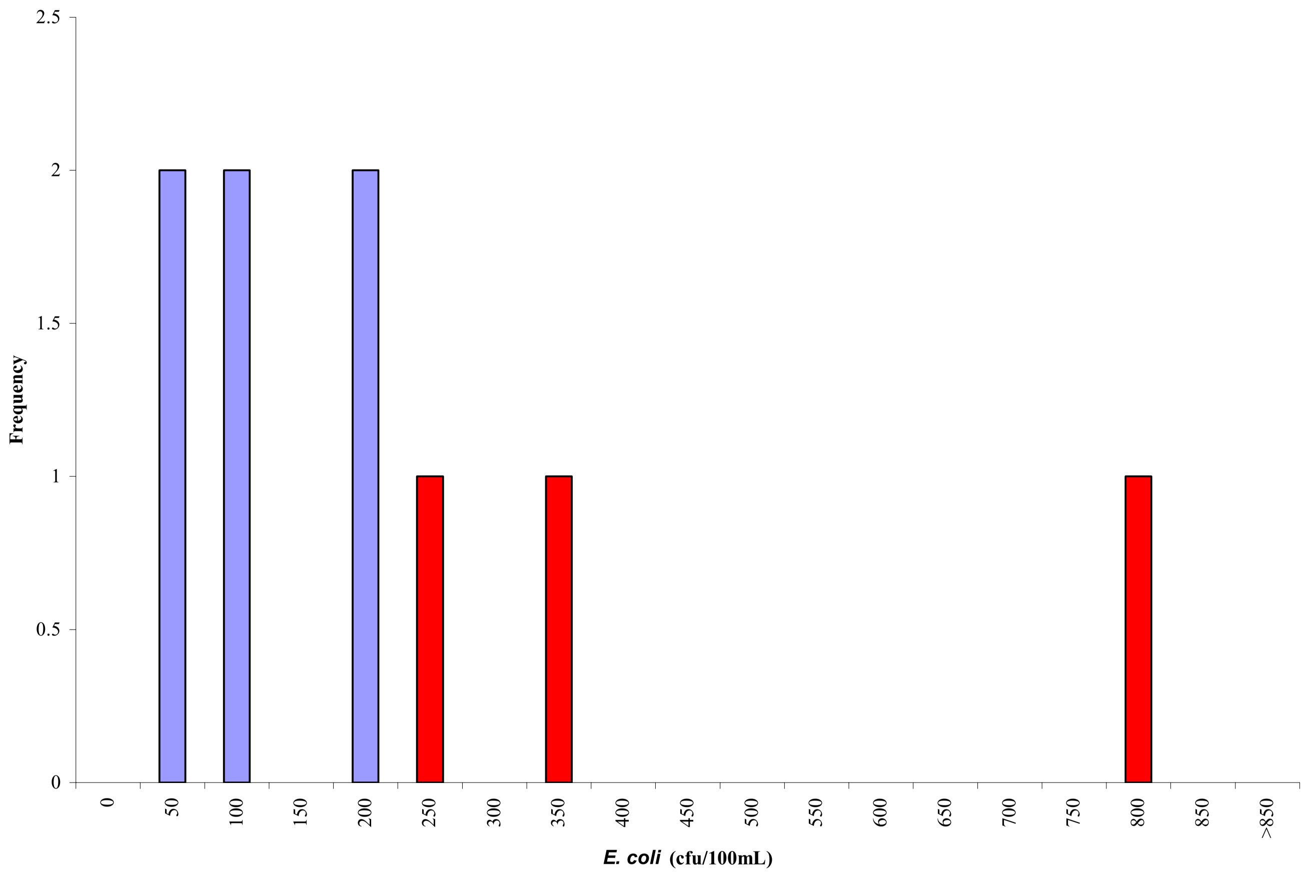

Figure A.16 Frequency analysis of *E. coli* concentrations at station 2-SGL001.00 in the Shingle Creek impairment for the period August 2002 to April 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100mL.

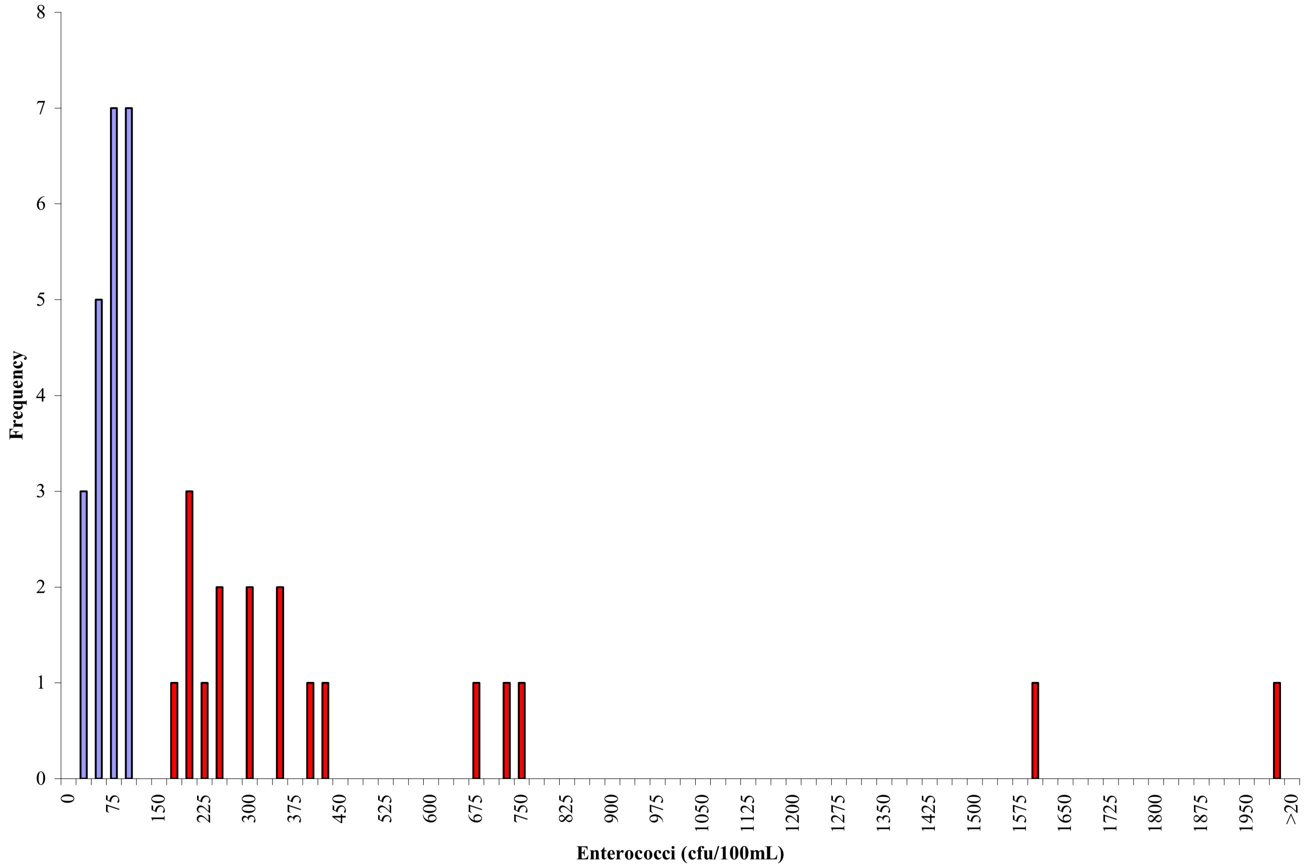

Figure A.17 Frequency analysis of *enterococci* concentrations at station 2-NAN019.14 in the Nansemond River impairment for the period March 2000 to December 2005.

*Red indicates a value which violates the listing standard of 104 cfu/100mL.

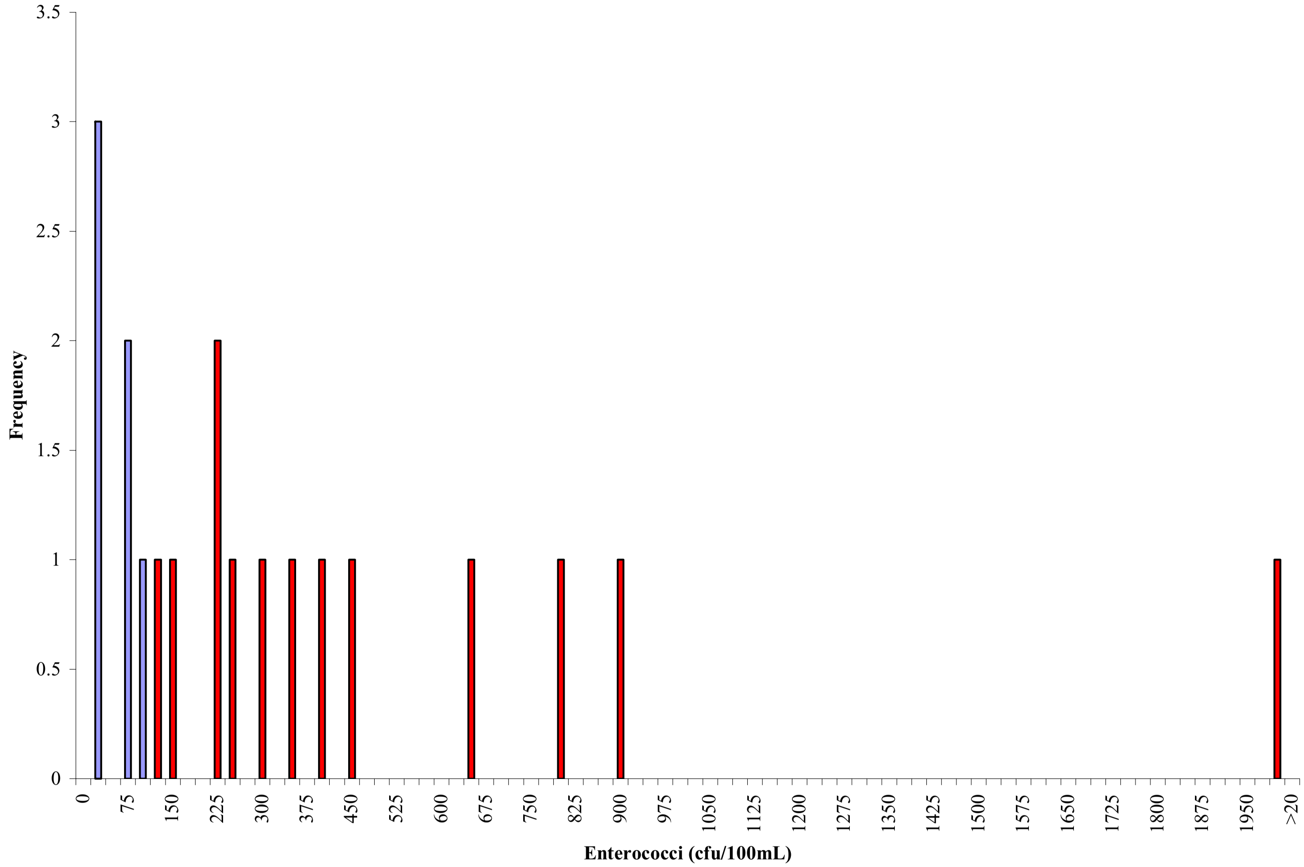

Figure A.18 Frequency analysis of *enterococci* concentrations at station 2-SGL001.00 in the Shingle Creek impairment for the period August 2002 to December 2005.

*Red indicates a value which violates the listing standard of 104 cfu/100mL.

APPENDIX B

FECAL COLIFORM LOADS IN EXISTING CONDITIONS

Table B.1 Current conditions of land applied fecal coliform load for Lake Meade Dam by land use (subwatersheds 1,2,5,3):

Land use	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
BarrenTrans	5.75E+11	5.19E+11	5.75E+11	5.56E+11	5.75E+11	5.56E+11	5.75E+11	5.75E+11	5.56E+11	5.75E+11	5.56E+11	5.75E+11	6.77E+12
Commercial	5.19E+12	4.69E+12	5.19E+12	5.02E+12	5.19E+12	5.02E+12	5.19E+12	5.19E+12	5.02E+12	5.19E+12	5.02E+12	5.19E+12	6.11E+13
Forest	4.25E+13	3.83E+13	4.25E+13	4.11E+13	4.25E+13	4.11E+13	4.25E+13	4.25E+13	4.11E+13	4.25E+13	4.11E+13	4.25E+13	5.00E+14
HIR	1.04E+12	9.41E+11	1.04E+12	1.01E+12	1.04E+12	1.01E+12	1.04E+12	1.04E+12	1.01E+12	1.04E+12	1.01E+12	1.04E+12	1.23E+13
LAX	1.86E+12	1.68E+12	2.21E+12	2.81E+12	2.90E+12	3.14E+12	3.25E+12	3.25E+12	2.81E+12	2.21E+12	2.13E+12	1.86E+12	3.01E+13
LIRUrbGrass	6.52E+12	5.89E+12	6.52E+12	6.31E+12	6.52E+12	6.31E+12	6.52E+12	6.52E+12	6.31E+12	6.52E+12	6.31E+12	6.52E+12	7.68E+13
PastureHay	8.47E+13	7.65E+13	1.43E+14	1.49E+14	1.52E+14	8.77E+13	9.04E+13	9.04E+13	8.09E+13	1.53E+14	1.50E+14	8.47E+13	1.34E+15
RowCrop	2.43E+13	2.35E+13	1.45E+14	1.55E+14	1.55E+14	1.76E+13	1.82E+13	1.82E+13	3.78E+13	1.55E+14	1.55E+14	2.43E+13	9.29E+14
Wetland	1.63E+14	1.47E+14	1.63E+14	1.58E+14	1.63E+14	1.58E+14	1.63E+14	1.63E+14	1.58E+14	1.63E+14	1.58E+14	1.63E+14	1.92E+15

Table B.2 Current conditions of land applied fecal coliform load for Nansemond River and tributaries by land use (subwatersheds 1,2,3,4,5,6,7):

Land use	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
BarrenTrans	1.64E+12	1.48E+12	1.64E+12	1.59E+12	1.64E+12	1.59E+12	1.64E+12	1.64E+12	1.59E+12	1.64E+12	1.59E+12	1.64E+12	1.93E+13
Commercial	6.58E+12	5.95E+12	6.58E+12	6.37E+12	6.58E+12	6.37E+12	6.58E+12	6.58E+12	6.37E+12	6.58E+12	6.37E+12	6.58E+12	7.75E+13
Forest	8.32E+13	7.51E+13	8.32E+13	8.05E+13	8.32E+13	8.05E+13	8.32E+13	8.32E+13	8.05E+13	8.32E+13	8.05E+13	8.32E+13	9.79E+14
HIR	1.12E+12	1.01E+12	1.12E+12	1.08E+12	1.12E+12	1.08E+12	1.12E+12	1.12E+12	1.08E+12	1.12E+12	1.08E+12	1.12E+12	1.31E+13
LAX	3.98E+12	3.59E+12	4.70E+12	5.96E+12	6.16E+12	6.66E+12	6.89E+12	6.89E+12	5.96E+12	4.70E+12	4.55E+12	3.98E+12	6.40E+13
LIRUrbGrass	1.01E+13	9.12E+12	1.01E+13	9.77E+12	1.01E+13	9.77E+12	1.01E+13	1.01E+13	9.77E+12	1.01E+13	9.77E+12	1.01E+13	1.19E+14
PastureHay	2.06E+14	1.86E+14	7.06E+14	7.08E+14	7.15E+14	2.04E+14	2.11E+14	2.11E+14	1.97E+14	7.16E+14	7.09E+14	2.06E+14	4.97E+15
RowCrop	4.15E+13	3.92E+13	6.09E+14	6.18E+14	6.19E+14	3.39E+13	3.50E+13	3.50E+13	5.55E+13	6.19E+14	6.18E+14	4.15E+13	3.37E+15
Wetland	2.24E+14	2.02E+14	2.24E+14	2.17E+14	2.24E+14	2.17E+14	2.24E+14	2.24E+14	2.17E+14	2.24E+14	2.17E+14	2.24E+14	2.64E+15

Table B.3 Current conditions of land applied fecal coliform load for Shingle Creek by land use (subwatershed 5):

Land use	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
BarrenTrans	3.72E+10	3.36E+10	3.72E+10	3.60E+10	3.72E+10	3.60E+10	3.72E+10	3.72E+10	3.60E+10	3.72E+10	3.60E+10	3.72E+10	4.38E+11
Commercial	4.58E+11	4.14E+11	4.58E+11	4.43E+11	4.58E+11	4.43E+11	4.58E+11	4.58E+11	4.43E+11	4.58E+11	4.43E+11	4.58E+11	5.39E+12
Forest	1.57E+12	1.42E+12	1.57E+12	1.52E+12	1.57E+12	1.52E+12	1.57E+12	1.57E+12	1.52E+12	1.57E+12	1.52E+12	1.57E+12	1.84E+13
HIR	7.38E+11	6.67E+11	7.38E+11	7.14E+11	7.38E+11	7.14E+11	7.38E+11	7.38E+11	7.14E+11	7.38E+11	7.14E+11	7.38E+11	8.69E+12
LAX	1.22E+11	1.10E+11	1.46E+11	1.88E+11	1.95E+11	2.12E+11	2.19E+11	2.19E+11	1.88E+11	1.46E+11	1.41E+11	1.22E+11	2.01E+12
LIRUrbGrass	1.41E+12	1.27E+12	1.41E+12	1.36E+12	1.41E+12	1.36E+12	1.41E+12	1.41E+12	1.36E+12	1.41E+12	1.36E+12	1.41E+12	1.66E+13
PastureHay	9.47E+12	8.55E+12	1.45E+13	2.44E+13	2.47E+13	9.07E+12	9.37E+12	9.37E+12	9.09E+12	2.48E+13	2.45E+13	9.47E+12	1.77E+14
RowCrop	1.16E+12	1.05E+12	6.19E+12	1.65E+13	1.65E+13	1.13E+12	1.16E+12	1.16E+12	1.13E+12	1.65E+13	1.65E+13	1.16E+12	8.01E+13
Wetland	7.85E+13	7.09E+13	7.85E+13	7.60E+13	7.85E+13	7.60E+13	7.85E+13	7.85E+13	7.60E+13	7.85E+13	7.60E+13	7.85E+13	9.25E+14

Table B.4 Current conditions of land applied fecal coliform load for Upper Nansemond River by land use (subwatersheds 1,2,5):

Land use	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
BarrenTrans	5.75E+11	5.19E+11	5.75E+11	5.56E+11	5.75E+11	5.56E+11	5.75E+11	5.75E+11	5.56E+11	5.75E+11	5.56E+11	5.75E+11	6.77E+12
Commercial	4.06E+12	3.66E+12	4.06E+12	3.92E+12	4.06E+12	3.92E+12	4.06E+12	4.06E+12	3.92E+12	4.06E+12	3.92E+12	4.06E+12	4.77E+13
Forest	4.05E+13	3.66E+13	4.05E+13	3.92E+13	4.05E+13	3.92E+13	4.05E+13	4.05E+13	3.92E+13	4.05E+13	3.92E+13	4.05E+13	4.77E+14
HIR	1.04E+12	9.41E+11	1.04E+12	1.01E+12	1.04E+12	1.01E+12	1.04E+12	1.04E+12	1.01E+12	1.04E+12	1.01E+12	1.04E+12	1.23E+13
LAX	1.64E+12	1.48E+12	1.96E+12	2.51E+12	2.59E+12	2.82E+12	2.91E+12	2.91E+12	2.51E+12	1.96E+12	1.89E+12	1.64E+12	2.68E+13
LIRUrbGrass	6.24E+12	5.63E+12	6.24E+12	6.04E+12	6.24E+12	6.04E+12	6.24E+12	6.24E+12	6.04E+12	6.24E+12	6.04E+12	6.24E+12	7.34E+13
PastureHay	7.75E+13	7.00E+13	1.29E+14	1.37E+14	1.39E+14	8.08E+13	8.33E+13	8.33E+13	7.41E+13	1.40E+14	1.37E+14	7.75E+13	1.23E+15
RowCrop	2.25E+13	2.19E+13	1.37E+14	1.47E+14	1.48E+14	1.59E+13	1.64E+13	1.64E+13	3.61E+13	1.48E+14	1.47E+14	2.25E+13	8.78E+14
Wetland	1.20E+14	1.09E+14	1.20E+14	1.16E+14	1.20E+14	1.16E+14	1.20E+14	1.20E+14	1.16E+14	1.20E+14	1.16E+14	1.20E+14	1.42E+15

Table B.5 Current conditions of land applied fecal coliform load for Western Branch by land use (subwatersheds 6,7):

Land use	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
BarrenTrans	7.51E+11	6.79E+11	7.51E+11	7.27E+11	7.51E+11	7.27E+11	7.51E+11	7.51E+11	7.27E+11	7.51E+11	7.27E+11	7.51E+11	8.85E+12
Commercial	5.42E+11	4.90E+11	5.42E+11	5.25E+11	5.42E+11	5.25E+11	5.42E+11	5.42E+11	5.25E+11	5.42E+11	5.25E+11	5.42E+11	6.38E+12
Forest	3.63E+13	3.27E+13	3.63E+13	3.51E+13	3.63E+13	3.51E+13	3.63E+13	3.63E+13	3.51E+13	3.63E+13	3.51E+13	3.63E+13	4.27E+14
HIR	6.24E+10	5.63E+10	6.24E+10	6.04E+10	6.24E+10	6.04E+10	6.24E+10	6.24E+10	6.04E+10	6.24E+10	6.04E+10	6.24E+10	7.35E+11
LAX	1.71E+12	1.54E+12	2.01E+12	2.54E+12	2.63E+12	2.84E+12	2.93E+12	2.93E+12	2.54E+12	2.01E+12	1.95E+12	1.71E+12	2.73E+13
LIRUrbGrass	1.59E+12	1.44E+12	1.59E+12	1.54E+12	1.59E+12	1.54E+12	1.59E+12	1.59E+12	1.54E+12	1.59E+12	1.54E+12	1.59E+12	1.87E+13
PastureHay	1.04E+14	9.40E+13	5.31E+14	5.27E+14	5.30E+14	1.00E+14	1.03E+14	1.03E+14	9.99E+13	5.31E+14	5.28E+14	1.04E+14	3.36E+15
RowCrop	1.21E+13	1.10E+13	4.44E+14	4.43E+14	4.44E+14	1.13E+13	1.17E+13	1.17E+13	1.27E+13	4.44E+14	4.43E+14	1.21E+13	2.30E+15
Wetland	1.90E+13	1.72E+13	1.90E+13	1.84E+13	1.90E+13	1.84E+13	1.90E+13	1.90E+13	1.84E+13	1.90E+13	1.84E+13	1.90E+13	2.24E+14

Table B.6 Monthly, directly deposited fecal coliform loads in each reach of the Lake Meade Dam (reaches 1,2,5,3):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	1	1.74E+13	1.57E+13	1.74E+13	1.69E+13	1.74E+13	1.69E+13	1.74E+13	1.74E+13	1.69E+13	1.74E+13	1.69E+13	1.74E+13	2.05E+14
Livestock	1	1.54E+09	1.39E+09	1.54E+09	1.49E+09	1.54E+09	1.49E+09	1.54E+09	1.54E+09	1.49E+09	1.54E+09	1.49E+09	1.54E+09	1.81E+10
Wildlife	1	2.86E+12	2.59E+12	2.86E+12	2.77E+12	2.86E+12	2.77E+12	2.86E+12	2.86E+12	2.77E+12	2.86E+12	2.77E+12	2.86E+12	3.37E+13
Human/Pet	2	1.38E+12	1.25E+12	1.38E+12	1.33E+12	1.38E+12	1.33E+12	1.38E+12	1.38E+12	1.33E+12	1.38E+12	1.33E+12	1.38E+12	1.62E+13
Livestock	2	5.43E+07	4.91E+07	5.43E+07	5.26E+07	5.43E+07	5.26E+07	5.43E+07	5.43E+07	5.26E+07	5.43E+07	5.26E+07	5.43E+07	6.40E+08
Wildlife	2	9.10E+11	8.22E+11	9.10E+11	8.81E+11	9.10E+11	8.81E+11	9.10E+11	9.10E+11	8.81E+11	9.10E+11	8.81E+11	9.10E+11	1.07E+13
Human/Pet	3	9.09E+12	8.21E+12	9.09E+12	8.80E+12	9.09E+12	8.80E+12	9.09E+12	9.09E+12	8.80E+12	9.09E+12	8.80E+12	9.09E+12	1.07E+14
Livestock	3	1.45E+08	1.31E+08	1.45E+08	1.40E+08	1.45E+08	1.40E+08	1.45E+08	1.45E+08	1.40E+08	1.45E+08	1.40E+08	1.45E+08	1.71E+09
Wildlife	3	2.03E+12	1.83E+12	2.03E+12	1.96E+12	2.03E+12	1.96E+12	2.03E+12	2.03E+12	1.96E+12	2.03E+12	1.96E+12	2.03E+12	2.39E+13
Human/Pet	5	3.56E+13	3.22E+13	3.56E+13	3.45E+13	3.56E+13	3.45E+13	3.56E+13	3.56E+13	3.45E+13	3.56E+13	3.45E+13	3.56E+13	4.20E+14
Livestock	5	3.92E+08	3.54E+08	3.92E+08	3.80E+08	3.92E+08	3.80E+08	3.92E+08	3.92E+08	3.80E+08	3.92E+08	3.80E+08	3.92E+08	4.62E+09
Wildlife	5	3.35E+12	3.03E+12	3.35E+12	3.25E+12	3.35E+12	3.25E+12	3.35E+12	3.35E+12	3.25E+12	3.35E+12	3.25E+12	3.35E+12	3.95E+13

Table B.7 Monthly, directly deposited fecal coliform loads in each reach of the Nansemond River and tributaries (reaches 1,2,3,4,5,6,7):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	1	1.74E+13	1.57E+13	1.74E+13	1.69E+13	1.74E+13	1.69E+13	1.74E+13	1.74E+13	1.69E+13	1.74E+13	1.69E+13	1.74E+13	2.05E+14
Livestock	1	1.54E+09	1.39E+09	1.54E+09	1.49E+09	1.54E+09	1.49E+09	1.54E+09	1.54E+09	1.49E+09	1.54E+09	1.49E+09	1.54E+09	1.81E+10
Wildlife	1	2.86E+12	2.59E+12	2.86E+12	2.77E+12	2.86E+12	2.77E+12	2.86E+12	2.86E+12	2.77E+12	2.86E+12	2.77E+12	2.86E+12	3.37E+13
Human/Pet	2	1.38E+12	1.25E+12	1.38E+12	1.33E+12	1.38E+12	1.33E+12	1.38E+12	1.38E+12	1.33E+12	1.38E+12	1.33E+12	1.38E+12	1.62E+13
Livestock	2	5.43E+07	4.91E+07	5.43E+07	5.26E+07	5.43E+07	5.26E+07	5.43E+07	5.43E+07	5.26E+07	5.43E+07	5.26E+07	5.43E+07	6.40E+08
Wildlife	2	9.10E+11	8.22E+11	9.10E+11	8.81E+11	9.10E+11	8.81E+11	9.10E+11	9.10E+11	8.81E+11	9.10E+11	8.81E+11	9.10E+11	1.07E+13
Human/Pet	3	9.09E+12	8.21E+12	9.09E+12	8.80E+12	9.09E+12	8.80E+12	9.09E+12	9.09E+12	8.80E+12	9.09E+12	8.80E+12	9.09E+12	1.07E+14
Livestock	3	1.45E+08	1.31E+08	1.45E+08	1.40E+08	1.45E+08	1.40E+08	1.45E+08	1.45E+08	1.40E+08	1.45E+08	1.40E+08	1.45E+08	1.71E+09
Wildlife	3	2.03E+12	1.83E+12	2.03E+12	1.96E+12	2.03E+12	1.96E+12	2.03E+12	2.03E+12	1.96E+12	2.03E+12	1.96E+12	2.03E+12	2.39E+13
Human/Pet	4	1.06E+13	9.60E+12	1.06E+13	1.03E+13	1.06E+13	1.03E+13	1.06E+13	1.06E+13	1.03E+13	1.06E+13	1.03E+13	1.06E+13	1.25E+14
Livestock	4	3.62E+08	3.27E+08	3.62E+08	3.50E+08	3.62E+08	3.50E+08	3.62E+08	3.62E+08	3.50E+08	3.62E+08	3.50E+08	3.62E+08	4.26E+09
Wildlife	4	2.50E+12	2.26E+12	2.50E+12	2.42E+12	2.50E+12	2.42E+12	2.50E+12	2.50E+12	2.42E+12	2.50E+12	2.42E+12	2.50E+12	2.95E+13
Human/Pet	5	3.56E+13	3.22E+13	3.56E+13	3.45E+13	3.56E+13	3.45E+13	3.56E+13	3.56E+13	3.45E+13	3.56E+13	3.45E+13	3.56E+13	4.20E+14
Livestock	5	3.92E+08	3.54E+08	3.92E+08	3.80E+08	3.92E+08	3.80E+08	3.92E+08	3.92E+08	3.80E+08	3.92E+08	3.80E+08	3.92E+08	4.62E+09
Wildlife	5	3.35E+12	3.03E+12	3.35E+12	3.25E+12	3.35E+12	3.25E+12	3.35E+12	3.35E+12	3.25E+12	3.35E+12	3.25E+12	3.35E+12	3.95E+13
Human/Pet	6	1.25E+13	1.13E+13	1.25E+13	1.21E+13	1.25E+13	1.21E+13	1.25E+13	1.25E+13	1.21E+13	1.25E+13	1.21E+13	1.25E+13	1.47E+14
Livestock	6	3.77E+09	3.41E+09	3.77E+09	3.65E+09	3.77E+09	3.65E+09	3.77E+09	3.77E+09	3.65E+09	3.77E+09	3.65E+09	3.77E+09	4.44E+10
Wildlife	6	2.39E+12	2.16E+12	2.39E+12	2.31E+12	2.39E+12	2.31E+12	2.39E+12	2.39E+12	2.31E+12	2.39E+12	2.31E+12	2.39E+12	2.81E+13
Human/Pet	7	4.45E+11	4.02E+11	4.45E+11	4.31E+11	4.45E+11	4.31E+11	4.45E+11	4.45E+11	4.31E+11	4.45E+11	4.31E+11	4.45E+11	5.24E+12
Livestock	7	4.23E+07	3.82E+07	4.23E+07	4.09E+07	4.23E+07	4.09E+07	4.23E+07	4.23E+07	4.09E+07	4.23E+07	4.09E+07	4.23E+07	4.97E+08
Wildlife	7	2.86E+11	2.58E+11	2.86E+11	2.77E+11	2.86E+11	2.77E+11	2.86E+11	2.86E+11	2.77E+11	2.86E+11	2.77E+11	2.86E+11	3.37E+12

Table B.8 Monthly, directly deposited fecal coliform loads in each reach of the Shingle Creek (reach 5):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	5	3.56E+13	3.22E+13	3.56E+13	3.45E+13	3.56E+13	3.45E+13	3.56E+13	3.56E+13	3.45E+13	3.56E+13	3.45E+13	3.56E+13	4.20E+14
Livestock	5	3.92E+08	3.54E+08	3.92E+08	3.80E+08	3.92E+08	3.80E+08	3.92E+08	3.92E+08	3.80E+08	3.92E+08	3.80E+08	3.92E+08	4.62E+09
Wildlife	5	3.35E+12	3.03E+12	3.35E+12	3.25E+12	3.35E+12	3.25E+12	3.35E+12	3.35E+12	3.25E+12	3.35E+12	3.25E+12	3.35E+12	3.95E+13

Table B.9 Monthly, directly deposited fecal coliform loads in each reach of the Upper Nansemond River (reaches 1,2,5):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	1	1.74E+13	1.57E+13	1.74E+13	1.69E+13	1.74E+13	1.69E+13	1.74E+13	1.74E+13	1.69E+13	1.74E+13	1.69E+13	1.74E+13	2.05E+14
Livestock	1	1.54E+09	1.39E+09	1.54E+09	1.49E+09	1.54E+09	1.49E+09	1.54E+09	1.54E+09	1.49E+09	1.54E+09	1.49E+09	1.54E+09	1.81E+10
Wildlife	1	2.86E+12	2.59E+12	2.86E+12	2.77E+12	2.86E+12	2.77E+12	2.86E+12	2.86E+12	2.77E+12	2.86E+12	2.77E+12	2.86E+12	3.37E+13
Human/Pet	2	1.38E+12	1.25E+12	1.38E+12	1.33E+12	1.38E+12	1.33E+12	1.38E+12	1.38E+12	1.33E+12	1.38E+12	1.33E+12	1.38E+12	1.62E+13
Livestock	2	5.43E+07	4.91E+07	5.43E+07	5.26E+07	5.43E+07	5.26E+07	5.43E+07	5.43E+07	5.26E+07	5.43E+07	5.26E+07	5.43E+07	6.40E+08
Wildlife	2	9.10E+11	8.22E+11	9.10E+11	8.81E+11	9.10E+11	8.81E+11	9.10E+11	9.10E+11	8.81E+11	9.10E+11	8.81E+11	9.10E+11	1.07E+13
Human/Pet	5	3.56E+13	3.22E+13	3.56E+13	3.45E+13	3.56E+13	3.45E+13	3.56E+13	3.56E+13	3.45E+13	3.56E+13	3.45E+13	3.56E+13	4.20E+14
Livestock	5	3.92E+08	3.54E+08	3.92E+08	3.80E+08	3.92E+08	3.80E+08	3.92E+08	3.92E+08	3.80E+08	3.92E+08	3.80E+08	3.92E+08	4.62E+09
Wildlife	5	3.35E+12	3.03E+12	3.35E+12	3.25E+12	3.35E+12	3.25E+12	3.35E+12	3.35E+12	3.25E+12	3.35E+12	3.25E+12	3.35E+12	3.95E+13

Table B.10 Monthly, directly deposited fecal coliform loads in each reach of the Western Branch (reaches 6,7):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	6	1.25E+13	1.13E+13	1.25E+13	1.21E+13	1.25E+13	1.21E+13	1.25E+13	1.25E+13	1.21E+13	1.25E+13	1.21E+13	1.25E+13	1.47E+14
Livestock	6	3.77E+09	3.41E+09	3.77E+09	3.65E+09	3.77E+09	3.65E+09	3.77E+09	3.77E+09	3.65E+09	3.77E+09	3.65E+09	3.77E+09	4.44E+10
Wildlife	6	2.39E+12	2.16E+12	2.39E+12	2.31E+12	2.39E+12	2.31E+12	2.39E+12	2.39E+12	2.31E+12	2.39E+12	2.31E+12	2.39E+12	2.81E+13
Human/Pet	7	4.45E+11	4.02E+11	4.45E+11	4.31E+11	4.45E+11	4.31E+11	4.45E+11	4.45E+11	4.31E+11	4.45E+11	4.31E+11	4.45E+11	5.24E+12
Livestock	7	4.23E+07	3.82E+07	4.23E+07	4.09E+07	4.23E+07	4.09E+07	4.23E+07	4.23E+07	4.09E+07	4.23E+07	4.09E+07	4.23E+07	4.97E+08
Wildlife	7	2.86E+11	2.58E+11	2.86E+11	2.77E+11	2.86E+11	2.77E+11	2.86E+11	2.86E+11	2.77E+11	2.86E+11	2.77E+11	2.86E+11	3.37E+12

Table B.11 Existing annual loads from land-based sources for the Lake Meade Dam (subwatersheds 1,2,5,3):

Source	BarrenTrans	Commercial	Forest	HIR	LAX	LIRUrbGrass	PastureHay	RowCrop	Water	Wetland
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E+10	0.00E+00
beef_calf	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.88E+13	0.00E+00	0.00E+00	0.00E+00
beef_stocker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.51E+11	0.00E+00	3.01E+14	0.00E+00	2.51E+10	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.12E+13	4.12E+13	0.00E+00	0.00E+00
dairy_calf	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.15E+12	3.89E+13	0.00E+00	0.00E+00
dairy_milker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.77E+13	3.20E+14	0.00E+00	0.00E+00
dairy_replacement	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.88E+13	2.31E+13	0.00E+00	0.00E+00
Deer	0.00E+00	0.00E+00	4.07E+13	0.00E+00	2.12E+11	1.88E+12	1.75E+13	2.97E+13	0.00E+00	4.87E+13
Duck	1.33E+08	1.73E+09	1.41E+10	2.18E+08	3.82E+08	2.16E+09	3.41E+09	3.82E+09	0.00E+00	7.71E+10
Goose	4.61E+09	6.00E+10	4.91E+11	7.58E+09	1.33E+10	7.50E+10	1.18E+11	1.33E+11	0.00E+00	2.68E+12
hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E+14	2.91E+14	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.05E+13	0.00E+00	3.88E+14	0.00E+00	0.00E+00	0.00E+00
Muskrat	2.75E+12	3.58E+13	2.93E+14	4.52E+12	7.91E+12	4.47E+13	7.07E+13	7.91E+13	0.00E+00	1.60E+15
people_with_straight_pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.48E+14	0.00E+00
Raccoon	4.01E+12	2.52E+13	1.66E+14	7.74E+12	1.20E+12	3.01E+13	6.47E+13	1.05E+14	0.00E+00	2.69E+14
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E+10	0.00E+00	5.52E+11	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	0.00E+00	1.58E+10	0.00E+00	2.06E+07	0.00E+00	1.69E+09	2.88E+09	0.00E+00	1.89E+10

Table B.12 Existing annual loads from land-based sources for the Nansemond River and tributaries (subwatersheds 1,2,3,4,5,6,7):

Source	BarrenTrans	Commercial	Forest	HIR	LAX	LIRUrbGrass	PastureHay	RowCrop	Water	Wetland
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.70E+10	0.00E+00
beef_calf	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.75E+14	0.00E+00	0.00E+00	0.00E+00
beef_stocker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.42E+11	0.00E+00	8.90E+14	0.00E+00	7.43E+10	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.12E+13	4.12E+13	0.00E+00	0.00E+00
dairy_calf	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.29E+12	4.13E+13	0.00E+00	0.00E+00
dairy_milker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E+13	3.43E+14	0.00E+00	0.00E+00
dairy_replacement	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E+14	2.50E+13	0.00E+00	0.00E+00
Deer	0.00E+00	0.00E+00	8.56E+13	0.00E+00	5.69E+11	2.89E+12	4.00E+13	5.83E+13	0.00E+00	7.33E+13
Duck	3.81E+08	2.21E+09	2.68E+10	2.44E+08	8.14E+08	3.33E+09	6.63E+09	7.29E+09	0.00E+00	1.05E+11
Goose	1.32E+10	7.68E+10	9.29E+11	8.46E+09	2.83E+10	1.16E+11	2.30E+11	2.53E+11	0.00E+00	3.64E+12
hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E+15	2.50E+15	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.29E+13	0.00E+00	8.13E+14	0.00E+00	0.00E+00	0.00E+00
Muskrat	7.89E+12	4.59E+13	5.55E+14	5.05E+12	1.69E+13	6.91E+13	1.37E+14	1.51E+14	0.00E+00	2.17E+15
People with straight pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.03E+15	0.00E+00
Raccoon	1.14E+13	3.16E+13	3.38E+14	8.08E+12	2.92E+12	4.68E+13	1.46E+14	2.02E+14	0.00E+00	3.85E+14
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.05E+10	0.00E+00	9.58E+11	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	0.00E+00	3.32E+10	0.00E+00	5.51E+07	0.00E+00	3.88E+09	5.66E+09	0.00E+00	2.84E+10

Table B.13 Existing annual loads from land-based sources for the Shingle Creek (subwatershed 5):

Source	BarrenTrans	Commercial	Forest	HIR	LAX	LIRUrbGrass	PastureHay	RowCrop	Water	Wetland
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E+09	0.00E+00
beef_calf	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.18E+13	0.00E+00	0.00E+00	0.00E+00
beef_stocker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.62E+10	0.00E+00	5.54E+13	0.00E+00	4.62E+09	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.12E+13	4.12E+13	0.00E+00	0.00E+00
dairy_calf	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
dairy_milker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
dairy_replacement	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Deer	0.00E+00	0.00E+00	2.00E+12	0.00E+00	8.02E+09	3.72E+11	1.21E+12	2.79E+12	0.00E+00	1.59E+13
Duck	5.51E+05	1.13E+08	4.75E+08	1.61E+08	2.22E+07	4.93E+08	9.61E+07	1.75E+08	0.00E+00	3.85E+10
Goose	1.91E+07	3.93E+09	1.65E+10	5.58E+09	7.72E+08	1.71E+10	3.34E+09	6.07E+09	0.00E+00	1.34E+12
hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.51E+13	2.51E+13	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.43E+12	0.00E+00	2.71E+13	0.00E+00	0.00E+00	0.00E+00
Muskrat	1.14E+10	2.34E+12	9.85E+12	3.33E+12	4.61E+11	1.02E+13	1.99E+12	3.62E+12	0.00E+00	7.97E+14
people_with_straight_pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.20E+14	0.00E+00
Raccoon	4.26E+11	3.05E+12	6.58E+12	5.36E+12	5.89E+10	5.95E+12	3.36E+12	7.29E+12	0.00E+00	1.10E+14
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.71E+09	0.00E+00	3.25E+10	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	0.00E+00	7.76E+08	0.00E+00	7.77E+05	0.00E+00	1.17E+08	2.70E+08	0.00E+00	6.17E+09

Table B.14 Existing annual loads from land-based sources for the Upper Nansemond River (subwatersheds 1,2,5):

Source	BarrenTrans	Commercial	Forest	HIR	LAX	LIRUrbGrass	PastureHay	RowCrop	Water	Wetland
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E+10	0.00E+00
beef_calf	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E+13	0.00E+00	0.00E+00	0.00E+00
beef_stocker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.34E+11	0.00E+00	2.80E+14	0.00E+00	2.34E+10	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.12E+13	4.12E+13	0.00E+00	0.00E+00
dairy_calf	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.15E+12	3.89E+13	0.00E+00	0.00E+00
dairy_milker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.77E+13	3.20E+14	0.00E+00	0.00E+00
dairy_replacement	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.88E+13	2.31E+13	0.00E+00	0.00E+00
Deer	0.00E+00	0.00E+00	3.98E+13	0.00E+00	1.86E+11	1.83E+12	1.60E+13	2.79E+13	0.00E+00	3.97E+13
Duck	1.33E+08	1.27E+09	1.33E+10	2.18E+08	3.16E+08	2.05E+09	2.81E+09	3.32E+09	0.00E+00	5.64E+10
Goose	4.61E+09	4.40E+10	4.63E+11	7.58E+09	1.10E+10	7.14E+10	9.77E+10	1.15E+11	0.00E+00	1.96E+12
hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.61E+14	2.61E+14	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E+13	0.00E+00	3.56E+14	0.00E+00	0.00E+00	0.00E+00
Muskrat	2.75E+12	2.62E+13	2.76E+14	4.52E+12	6.56E+12	4.26E+13	5.83E+13	6.87E+13	0.00E+00	1.17E+15
people_with_straight_pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.41E+14	0.00E+00
Raccoon	4.01E+12	2.15E+13	1.60E+14	7.74E+12	1.04E+12	2.90E+13	5.74E+13	9.68E+13	0.00E+00	2.07E+14
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.65E+10	0.00E+00	5.03E+11	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	0.00E+00	1.54E+10	0.00E+00	1.81E+07	0.00E+00	1.56E+09	2.70E+09	0.00E+00	1.54E+10

Table B.15 Existing annual loads from land-based sources for the Western Branch (subwatersheds 6,7):

Source	BarrenTrans	Commercial	Forest	HIR	LAX	LIRUrbGrass	PastureHay	RowCrop	Water	Wetland
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E+10	0.00E+00
beef_calf	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.02E+14	0.00E+00	0.00E+00	0.00E+00
beef_stocker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.49E+11	0.00E+00	5.39E+14	0.00E+00	4.49E+10	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
dairy_calf	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.37E+11	2.47E+12	0.00E+00	0.00E+00
dairy_milker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E+12	2.31E+13	0.00E+00	0.00E+00
dairy_replacement	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.96E+12	1.86E+12	0.00E+00	0.00E+00
Deer	0.00E+00	0.00E+00	4.08E+13	0.00E+00	3.04E+11	5.13E+11	1.86E+13	2.28E+13	0.00E+00	1.30E+13
Duck	1.83E+08	1.75E+08	1.11E+10	2.40E+07	3.40E+08	4.99E+08	2.20E+09	2.09E+09	0.00E+00	7.85E+09
Goose	6.36E+09	6.08E+09	3.87E+11	8.34E+08	1.18E+10	1.73E+10	7.64E+10	7.26E+10	0.00E+00	2.73E+11
hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.14E+15	2.14E+15	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E+13	0.00E+00	3.43E+14	0.00E+00	0.00E+00	0.00E+00
Muskrat	3.80E+12	3.63E+12	2.31E+14	4.98E+11	7.05E+12	1.03E+13	4.56E+13	4.33E+13	0.00E+00	1.63E+14
people_with_straight_pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.52E+14	0.00E+00
Raccoon	5.04E+12	2.75E+12	1.55E+14	2.36E+11	1.43E+12	7.87E+12	6.31E+13	7.12E+13	0.00E+00	4.80E+13
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.54E+10	0.00E+00	2.92E+11	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	0.00E+00	1.58E+10	0.00E+00	2.94E+07	0.00E+00	1.81E+09	2.21E+09	0.00E+00	5.03E+09

Table B.16 Existing annual loads from direct-deposition sources for the Lake Meade Dam (reaches 1,2,5,3):

Source	Annual Total Loads (cfu/yr)
Beaver	3.19E+10
beef_calf	0.00E+00
beef_stocker	2.51E+10
broilers	0.00E+00
dairy_calf	0.00E+00
dairy_milker	0.00E+00
dairy_replacement	0.00E+00
Deer	6.94E+10
Duck	4.22E+09
Goose	9.65E+10
hog	0.00E+00
horse	0.00E+00
Muskrat	1.06E+14
people_with_straight_pipes	7.48E+14
Raccoon	1.71E+12
sheep	0.00E+00
Turkey	1.97E+07

Table B.17 Existing annual loads from direct-deposition sources for the Nansemond River and tributaries (reaches 1,2,3,4,5,6,7):

Source	Annual Total Loads (cfu/yr)
Beaver	5.70E+10
beef_calf	0.00E+00
beef_stocker	7.43E+10
broilers	0.00E+00
dairy_calf	0.00E+00
dairy_milker	0.00E+00
dairy_replacement	0.00E+00
Deer	1.30E+11
Duck	6.60E+09
Goose	1.51E+11
hog	0.00E+00
horse	0.00E+00
Muskrat	1.65E+14
people_with_straight_pipes	1.03E+15
Raccoon	2.98E+12
sheep	0.00E+00
Turkey	3.56E+07

Table B.18 Existing annual loads from direct-deposition sources for the Shingle Creek (reach 5):

Source	Annual Total Loads (cfu/yr)
Beaver	1.90E+09
beef_calf	0.00E+00
beef_stocker	4.62E+09
broilers	0.00E+00
dairy_calf	0.00E+00
dairy_milker	0.00E+00
dairy_replacement	0.00E+00
Deer	1.12E+10
Duck	1.56E+09
Goose	3.56E+10
hog	0.00E+00
horse	0.00E+00
Muskrat	3.91E+13
people_with_straight_pipes	4.20E+14
Raccoon	3.57E+11
sheep	0.00E+00
Turkey	3.67E+06

Table B.19 Existing annual loads from direct-deposition sources for the Upper Nansemond River (reaches 1,2,5):

Source	Annual Total Loads (cfu/yr)
Beaver	2.60E+10
beef_calf	0.00E+00
beef_stocker	2.34E+10
broilers	0.00E+00
dairy_calf	0.00E+00
dairy_milker	0.00E+00
dairy_replacement	0.00E+00
Deer	6.28E+10
Duck	3.28E+09
Goose	7.50E+10
hog	0.00E+00
horse	0.00E+00
Muskrat	8.23E+13
people_with_straight_pipes	6.41E+14
Raccoon	1.48E+12
sheep	0.00E+00
Turkey	1.76E+07

Table B.20 Existing annual loads from direct-deposition sources for the Western Branch (reaches 6,7):

Source	Annual Total Loads (cfu/yr)
Beaver	1.40E+10
beef_calf	0.00E+00
beef_stocker	4.49E+10
broilers	0.00E+00
dairy_calf	0.00E+00
dairy_milker	0.00E+00
dairy_replacement	0.00E+00
Deer	4.80E+10
Duck	1.22E+09
Goose	2.78E+10
hog	0.00E+00
horse	0.00E+00
Muskrat	3.05E+13
people_with_straight_pipes	1.52E+14
Raccoon	9.10E+11
sheep	0.00E+00
Turkey	1.25E+07

APPENDIX C

TMDLs FOR FUTURE CONDITIONS

Table C.1 Future scenario for average annual enterococci bacterial loads (cfu/year) in the Nansemond River watershed VADEQ impairments.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Shingle Creek (sub 5)	6.63E+10	1.05E+13	*Implicit*	1.05E+13
VAR040044	*6.63E+10*			
Upper Nansemond (sub 1,2,5)	2.34E+11	5.79E+13		5.82E+13
VA0021709	*1.09E+10*			
VA0086134	*1.57E+11*			
VAR040044	*6.63E+10*			
Lake Meade (sub 1,2,3,5)	2.34E+11	4.24E+13		4.27E+13
VA0021709	*1.09E+10*			
VA0086134	*1.57E+11*			
VAR040044	*6.63E+10*			

Table C.2 Future scenario for average annual fecal coliform bacterial loads (cfu/year) in the Nansemond River watershed VDH impairments.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Shingle Creek (sub 5)	2.78E+09	1.05E+13	*Implicit*	1.05E+13
VAR040044	*2.78E+09*			
Nansemond R. and Tributaries (all subsheds)	1.31E+11	9.38E+12		9.51E+12
VA0021709	*5.29E+09*			
VA0027138	*1.27E+10*			
VA0027146	*1.13E+10*			
VA0069302	*9.40E+09*			
VA0086134	*7.63E+10*			
VAG403000	*5.29E+08*			
VAR040044	*1.58E+10*			